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THE STRATTON RIDGE SALT DOME, BRAZORIA COUNTY, TEXAS[1]

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ABSTRACT

The Stratton Ridge salt dome is a characteristic Gulf Coast salt dome. It has a low topographic mound. Salt and cap rock have been drilled into in many wells. The dome has been delineated roughly by deep wells on three sides. It is elongated in a northeast-southwest direction. The Oligocene and Miocene beds are sharply upthrust, do not extend over the top of the dome, and near the salt are overlain conformably by the Pliocene beds, all but the lower beds of which lie fairly flat across the top of the salt. The stratigraphic section (Recent to Vicksburg Oligocene) has been worked in considerable detail by microscopic study. Lists are given of the occurrence of the microscopic and megascopic fossils. Upthrust of the salt core took place during or just prior to the Lower Oligocene, but most of the deformation came between the Oligocene and Early Pliocene. Although many tests have been put down, only two small producers have been obtained, from around 4,300 feet. Commercial production has not been established.

INTRODUCTION

LOCATION

The Stratton Ridge salt dome is in the west half of the Jared E. Groce five-League Grant, in the southern part of Brazoria County, Texas, about 10 miles south of Angleton, and 7 miles north of Freeport. Both of these towns are served by the Houston and Brazos Valley Railroad. The dome is about midway between Hoskins Mound on the north and Bryan Heights on the south, both in Brazoria County.

[1] Published by permission of Mr. E. T. Dumble, consulting geologist for the Southern Pacific Company.

HISTORY

After the discovery of oil at Spindletop in 1901, all similar structures assumed interest and value as being indicative of potential oil fields. The existence of the topographic high now called Stratton Ridge was doubtless known for some time before active prospecting began there, but it was not until February, 1913, that drilling commenced on this dome. The attention of J. Dannenbaum, of Houston, had been attracted to this area by the topography and the presence of gas in a water well near Stubblefield Lake. Between February and July, 1913, two wells were drilled by Mr. Dannenbaum on the Stratton farm near the top of the ridge. These two wells were abandoned or lost at 1,058 and 854 feet respectively. Neither produced oil nor penetrated the salt. They did, however, prove the presence of gypsum and anhydrite on this dome, which induced further exploration. Well No. 2 reported a gas show at 839 feet. These wells undoubtedly would have encountered the salt had they been drilled to 1,300 feet.

The next development at Stratton Ridge was in 1915–16, when Farish *et al.* drilled three wells, two on the Seaburn farm and one on the Tolar and Dannenbaum 517-acre tract. These were well down on the east side of the ridge, and though all were drilled to more than 2,000 feet, none of them encountered salt. Seaburn No. 2 is reported to have had an oil show at 1,920 to 1,950 feet, and a gas show from 2,115 to 2,150 feet. The total depth of this well was 2,758 feet, and was the deepest test of the three.

Between August, 1917, and April, 1919, the Roxana Petroleum Corporation drilled four wells on the south end of the ridge. The first three finished in gypsum or anhydrite, and the fourth penetrated the salt at 1,334 feet. This was the first well drilled into salt at Stratton Ridge.

Since the first part of 1919, the Freeport Sulphur Company has carried on an almost continuous drilling campaign on the northeast end of the ridge, with twelve wells on the Tolar and Dannenbaum tract and three on the Seaburn farm. Tolar and Dannenbaum No. 9, completed May 12, 1922, had good shows of oil and gas from 3,100 to 4,300 feet, and the well flowed at a reported rate of 1,200 to 1,500 barrels for about a week, when it sanded up, and though worked

over for some time, never made a commercial well. Tolar and Dannenbaum No. 11 is one of the two producing wells at Stratton Ridge. It was completed in 1923 at a total depth of 4,386 feet, was put on the pump about November 1 of that year, and averages about 75 barrels a week.

The Humble Oil and Refining Company took an active interest in development at Stratton Ridge from June, 1919, to April, 1921, drilling six wells on the Seaburn land, on the south and east sides of the ridge. This company also drilled three dry wells on the west side of the ridge, two on the Brock and one on the Shea and Storrie tracts.

About December, 1919, and February, 1920, the Texas Company drilled two dry holes a mile or two west of Stratton Ridge on their Cochran and McClure leases. About this time, also, the Castell Oil Company, drilling on the Storrie farm on top of the ridge, reported a strong gas blow-out at 750 feet.

Between August 1 and November 16, 1922, the Empire Gas and Fuel Company drilled unsuccessfully to 4,671 feet in their Wilson No. 1 at the north end of the ridge.

The Fairchild Petroleum Company (C. C. Cannan *et al.*) completed their Boggs No. 1 at 4,575 feet as a dry hole at the north end of the ridge during the latter part of 1923. On March 7, 1924, Boggs No. 2 was completed at 4,287 feet and flowed about 1,500 to 2,000 barrels of oil and some water for a few days. It is now pumping, but the amount of production is not known. A total of thirty-eight wells have been drilled at Stratton Ridge. Wells now drilling are the Freeport Sulphur Company's No. 12, Tolar and Dannenbaum at the north end of the ridge, and the Associated Oil Company's Perry No. 1 at the south end of the ridge, near Chubb Lake.

PHYSIOGRAPHY

The Gulf Coastal Plain has been divided by some writers into two divisions. The upper or interior division ranges from 165 to 340 feet in elevation and slopes gently seaward at the rate of 1 or 2 feet per mile. Along the immediate coast and for several miles inland, the lower division shows an even gentler slope of less than 1 foot per mile seaward.

Rising from this lower, featureless plain are several prominent mounds or dome-shaped hills of varying heights and dimensions, belonging to what is known as the Coastal Mound class of salt domes. Stratton Ridge is one of these. Others in the immediate vicinity are

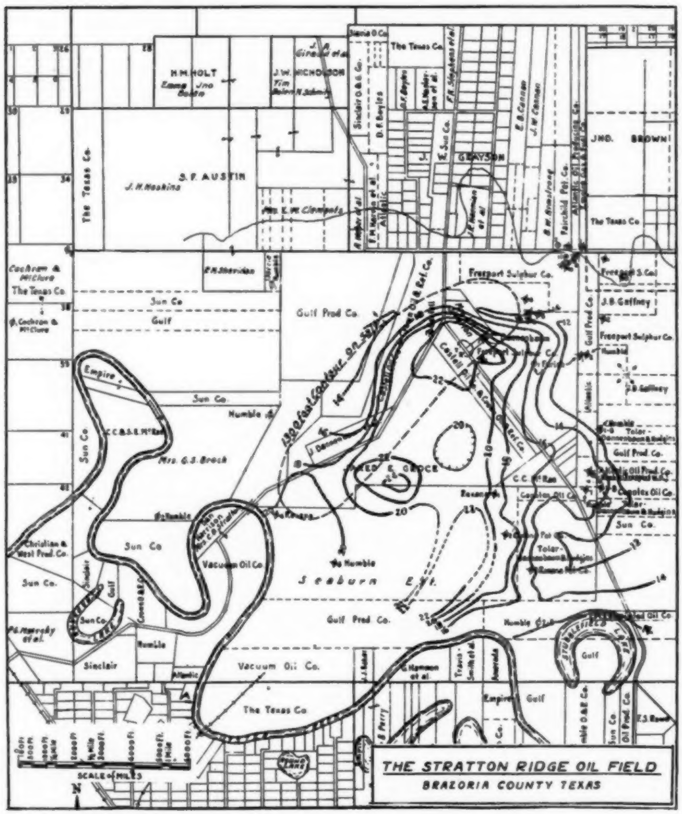


FIG. 1.—Topography of north end of Stratton Ridge Salt Dome. Contour interval, 2 feet; datum, sea-level.

West Columbia, Damon Mound, Hoskins Mound, and Bryan Mound in Brazoria County, and Big Hill in Matagorda County.

The salt-dome mound known as Stratton Ridge (Fig. 1), on account of its somewhat elongated form, is a poorly defined ridge with

a flat top and relatively steep sides. A slight depression is noted on top and near the center of the ridge. The long axis of the ridge trends about N. 30°E. This axis if extended would pass through Hoskins Mound 12 miles to the northeast and through Bryan Mound 12 miles to the southwest. The ridge is about 3.5 miles long from northeast to southwest, and about 2 miles wide across its shorter axis. It has a general elevation above sea-level of about 20 feet, though at one or two points its summit reaches 25 feet. The country about the ridge is low, flat, and marshy. Oyster Creek flows in a meandering course across the south end of the ridge, and Big Slough cuts across the north end.

A number of small, semicircular ponds or "ox-bows" such as Stubblefield Lake, Chubb Lake, and Barbara Lake are old meanders of Oyster Creek. These are all shallow ponds and are frequently dry in summer.

The age of the salt-dome mound as we now see it is probably Pleistocene or Recent.

SURFACE GEOLOGY

The areal geology of the region as a whole is simple and needs only be briefly stated here. The surface formations are:[1] (1) Recent material. A series of Recent sands, gravel, and river alluvium extends along the coast and up Brazos River and larger streams for varying distances and with different widths. On the coast the Recent materials appear as a strip of marshy country about 6 miles wide extending from Chocolate Bayou westward to and beyond Brazos River. This marshy strip of land envelops the three mounds of Hoskins, Stratton Ridge, and Bryan Heights. Big Hill, in Matagorda County, may also be included in this group. The immediate coast or shoreline is a mixture of sand with an occasional lens of clay. (2) Pleistocene. This series, generally known as the Beaumont clays, lies north of and in places apparently grades into the belt of marshy country occupied by the Recent material. The Beaumont clays appear as a broad belt of black, brown, and dark blue clays with sand lenses and nests of calcareous nodules. This series forms heavy, dark-colored or black soil. The clays envelop the West Columbia and Damon Mound domes.

[1] Data largely from private report by William Kennedy.

These are the surface formations with which the Stratton Ridge salt dome comes in contact. The underlying beds, or their inland equivalents, outcrop far to the north and west and will be treated in a later section of this paper.

SUBSURFACE GEOLOGY

General knowledge of underground conditions at Stratton Ridge has been gained from study of all available drillers' logs and from paleontological data derived from study of cuttings and cores secured from certain wells drilled by the Freeport Sulphur Company, the Roxana Petroleum Corporation, and the Humble Company.

From its general structure and the presence of gypsum, anhydrite, and salt, Stratton Ridge may be classed as a true salt dome, but one of peculiar shape and extraordinary areal extent.

THE SALT CORE

In form, the salt core at Stratton Ridge appears to be long, narrow, flat-topped, and rather steep-sided. The north and east sides of the salt core have been shown by drilling to be steep, but what the slope on the south and west may be is not definitely known. Nine wells have been drilled to the salt on this dome, six scattered over the top of the ridge and three on the northeast end. The six wells drilled on top of the ridge encountered the salt at a depth of slightly over 1,300 feet, and the 1,300-foot contour drawn on the salt, as found in these six wells, outlines the top of the salt core fairly well (Figs. 1 and 2), except at the extreme south end, where no wells have been drilled through the gypsum. The top of the salt core as now known has the shape of a long, narrow ellipse, with the long axis extending about 2 miles N. 55°E., roughly paralleling the coast-line at this point. The short axis of the salt core extends about $\frac{3}{4}$ mile northwest and southeast.

The relation of the top of the known salt core to the topographic ridge is shown in Figure 1, where the salt appears to lie somewhat down the northwest flank of the surface ridge. The relation of the salt core to the overlying gypsum and anhydrite cap is shown in Figure 2.

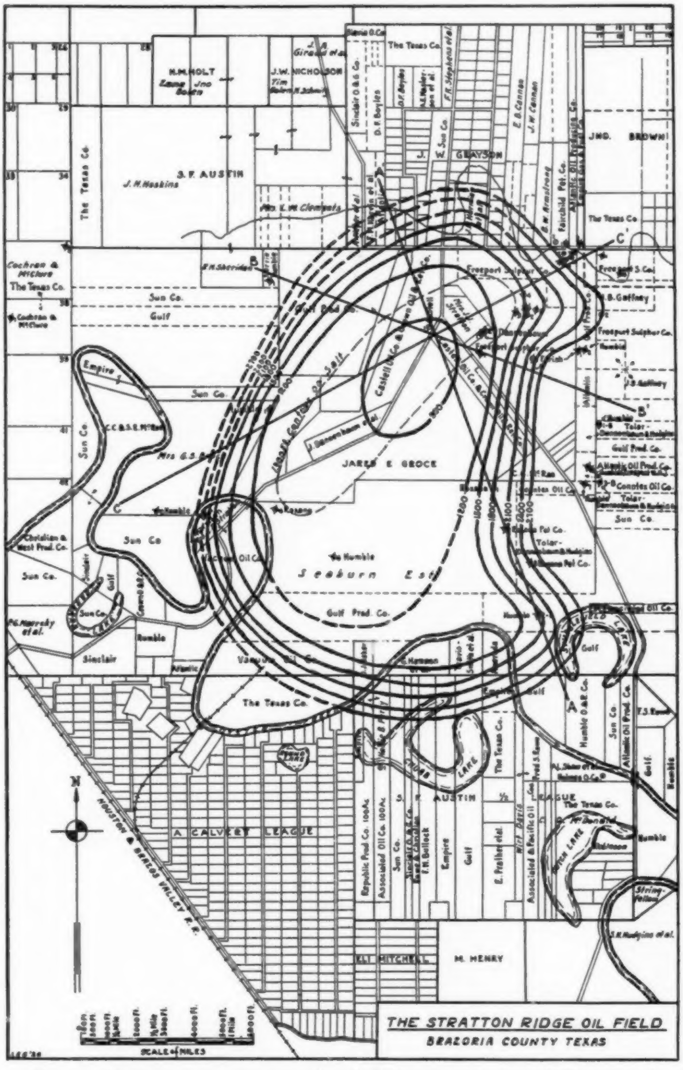


FIG. 2.—Contours on gypsum and anhydrite cap, Stratton Ridge salt dome. Contours based on elevation below sea-level. Contour interval, 300 feet.

The following wells have encountered salt, the first six near the top of the dome, the last three on the northeast end of the dome.

Company	Well	Depth to Salt
		Feet
Freeport Sulphur Company........	No. 1 Tolar and Dannenbaum	1,308
Freeport Sulphur Company........	No. 2 Tolar and Dannenbaum	1,316
Freeport Sulphur Company........	No. 4 Tolar and Dannenbaum	1,319
Roxana Petroleum Corporation.....	No. 4 Seaburn	1,334
Humble Oil and Refining Company..	No. 1 Brock	1,471
Castell..........................	No. 1 Storrie	1,250–1,300±
Freeport Sulphur Company........	No. 10 Tolar and Dannenbaum	2,633
Freeport Sulphur Company........	No. 1 Seaburn	4,765
Freeport Sulphur Company........	No. 2 Seaburn	2,473

The steep dip on the salt at the northeast end of the ridge is well shown by the records of the Freeport Sulphur Company's Tolar and Dannenbaum Nos. 8 and 10 (Fig. 5), the former being 150 feet north of the latter. Well No. 10 entered salt at 2,633 feet and continued to 3,255 feet, where the well was abandoned; No. 8 was drilled to 3,142 feet and showed no salt at that depth. This indicates an essentially vertical side to the salt core between these two wells. Section C–C′ (Figs. 2 and 3) passes through the Freeport's Tolar and Dannenbaum Nos. 4 and 10 and Seaburn No. 1 at the northeast end of the ridge. The difference in elevation on the salt between Tolar and Dannenbaum No. 4 and Seaburn No. 1, about 3,500 feet apart, amounts to 3,446 feet, indicating an average dip of about 45 degrees toward the northeast. The dip between Tolar and Dannenbaum No. 10 and Seaburn No. 1, however, is somewhat steeper than the dip between Tolar and Dannenbaum Nos. 4 and 10. Section B–B′ (Figs. 2 and 3) passes through the Freeport's Tolar and Dannenbaum No. 1 and Farish's Tolar and Dannenbaum No. 1 on the east side of the ridge. Freeport No. 1 showed salt at 1,308, while the Farish well, 1,800 feet to the east, showed no dome material when abandoned at 2,082 feet.

An irregularity in the salt core is noted at the northeast end of the dome near the Freeport's Seaburn No. 2. This well found the salt at 2,473 and drilled into it 100 feet. The Seaburn well is 2,750 feet east of the Tolar and Dannenbaum No. 2, which encountered the salt at 1,316 feet, and is 2,150 feet south of the Seaburn No. 1, which en-

countered the salt at 4,765 feet. Farish's No. 2 Seaburn, only 1,500 feet south of the Freeport's Seaburn No. 2, drilled to 2,758 feet, but did not encounter any salt, finishing in "sandy gyp." It is believed that the Freeport's Seaburn No. 2 is located on a narrow steep-sided ridge of solid salt projecting from the main core and plunging eastward. This plunging ridge or "nose" is reflected in the overlying gypsum cap and also to some extent in the surface topography.

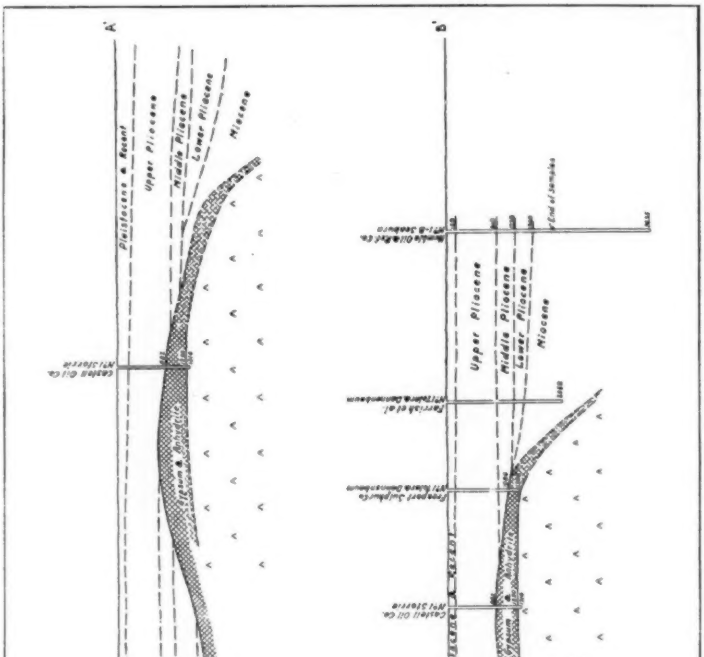
On the west and south sides of the ridge little work giving a clue to the structure of the salt has been done. The Humble's Brock No. 1 and the Roxana's Seaburn No. 4 encountered salt and are probably close to the edge of the flat top of the salt core. The Humble's Shea-Storrie No. 1 on the northwest side of the dome reached 4,086 feet without finding salt or gypsum, and their Brock No. 2 was drilled to 2,904 and found no dome material at that depth. These wells seem to indicate a steep west side to the salt core, but definite information is lacking until further drilling is done here. The position of the salt on the south side is equally problematical.

CAP

Above the main salt core at Stratton Ridge is a gypsum and anhydrite cap of irregular thickness, like an inverted saucer in form,[1] thickest toward the center and gradually thinning toward the edges. The wells along Section C–C[1] (Figs. 2 and 3) illustrate this condition. The Freeport Sulphur Company's Tolar and Dannenbaum No. 1 and the Castell Oil Company's Storrie No. 1, drilled near the top of the ridge, both show about 400 feet of gypsum. The Humble's No. 1 Brock, about 1¼ miles southwest of the Castell well, shows 169 feet of gypsum, and the Freeport's Tolar and Dannenbaum No. 4, 3,500 feet northeast of the Castell well, shows about 90 feet. Freeport's Tolar and Dannenbaum No. 10, on the northeast flank of the salt, records only 16 feet of gypsum, and their Seaburn No. 1, farthest northeast, enters the salt at 4,765 without recording any gypsum at all.

Sixteen wells at Stratton Ridge have drilled into gypsum and anhydrite. In some of the wells, especially those on the top of the ridge near the north end, the gypsum appears to be broken into two

[1] Private report by William Kennedy.


A
A'
Pleistocene & Recent
Upper Pliocene
Middle Pliocene
Lower Pliocene
Miocene
B
B'
Pleistocene & Recent
Upper Pliocene
Middle Pliocene
Lower Pliocene
Miocene

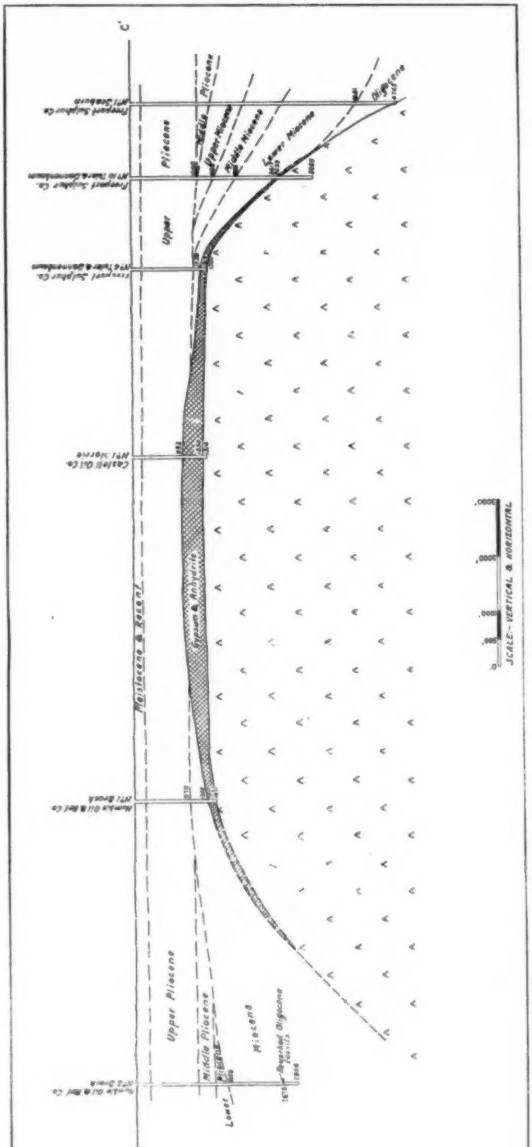


FIG. 3.—Structural sections through the dome

or more beds separated by sand or lime. In other wells, especially at the south end of the ridge, the gypsum seems to be a solid bed or interstratified with thin layers of anhydrite. These conditions may be illustrated by the driller's logs of some of the wells.

The log of the Freeport Sulphur Company's Tolar and Dannenbaum No. 1, near the crest of the ridge, shows the following conditions:

	Thickness	Depth
	Feet	Feet
Gypsum	101	1,011
Sand and shale	5	1,016
Gypsum	10	1,026
Sand rock	20	1,046
Gypsum	6	1,052
Boulders	10	1,062
Rock	22	1,084
Gypsum	185	1,269
Sand	6	1,275
Gypsum	33	1,308
Salt	....	....

In No. 2 of the same company's wells on this lease, 7 feet of lime occur in the middle of the gypsum bed. The log shows:

	Thickness	Depth
	Feet	Feet
Gypsum	40	1,252
Lime	7	1,259
Gypsum	57	1,316
Salt	....	....

Well No. 4, however, only 500 feet from No. 2, shows solid gypsum from 1,238 to 1,319 feet, underlying a series of gumbos with some lime rock. Salt was encountered at 1,319 feet.

Tolar and Dannenbaum No. 6 again shows the divided condition of the gypsum. The log is as follows:

	Thickness	Depth
	Feet	Feet
Gumbo, shale, and lime	138	1,292
Lime	28	1,320
Calcite	6	1,326
Blue lime	12	1,338
Gypsum	....	....

At the southern end of the ridge, the four wells drilled by the Roxana all encountered the gypsum, but only No. 4 drilled through it. Well No. 1 shows solid gypsum from 1,655 to 1,686 feet. In the No. 2, 3, and 4 wells the log shows the following conditions:

Roxana No. 2	Thickness	Depth
	Feet	Feet
Lime	9	1,851
Anhydrite and some lime	3	1,854
Gypsum	101	1,955
Roxana No. 3		
Clay	37	2,490
Anhydrite	32	2,522
Roxana No. 4		
Lime and gypsum	9	1,003
Anhydrite	17	1,020
Gypsum	293	1,313
Gypsum and salt	21	1,334
Rock salt	....	....

In the Humble's Seaburn No. 5, at the south end of the ridge, the gypsum appears in the form of blue and white bands from 1,053 to 1,121. Lime and gypsum mixed also occur from 1,008 to 1,023. The log shows:

	Thickness	Depth
	Feet	Feet
Lime and gypsum	15	1,023
Sand rock	12	1,035
Rock	10	1,045
Gypsum and shell	8	1,053
Solid gypsum	68	1,121

An irregularity in the depth to the gypsum is found at the southeast end of the ridge (Sec. A–A′, Fig. 2). The Humble Company's Seaburn B-2 encountered gypsum at 1,609 feet and continued in it for nearly 200 feet. This well is 2,000 feet south of the Roxana's No. 3, which found gypsum first at 2,490 feet.

So far as it has been drilled into, the gypsum has been shown to be close-grained, hard, and compact, especially the thicker beds. The broken, cavernous conditions found in some of the domes, and the large flows of black sulphur water and hydrogen sulphide gas are absent. It may also be noted here that since sulphur is of secondary origin and due to the destruction of the gypsum, the prospects for

finding sulphur on this dome are poor.[1] No definite limestone cap appears above the gypsum horizon on this dome, but for several hundred feet above the gypsum a series of interbedded limestones, sands, and gumbos is shown in many of the well logs.

STRUCTURE OF SURROUNDING SEDIMENTS

Information regarding the various formations penetrated by the drill on the Stratton Ridge salt dome has been acquired through microscopic study of well cuttings and cores, this work being done by the paleontological department of the Rio Bravo Oil Company. The data at hand are not sufficiently complete to permit making detailed sections of the formations, but the larger divisions may be recognized even though hard-and-fast lines cannot be drawn between them. This lack of definiteness is due mainly to three factors: (1) The well samples were in many cases cuttings rather than cores, especially in those earlier wells drilled before coring became common; (2) complete sets of samples were seldom available from any given well; (3) further, the paleontological data show that conditions of deposition here were unique and different from those found at any other coastal dome from which material has been studied. The evidence points to a state of shallow marine submergence, with frequent incursions and withdrawals of the sea in the vicinity of this dome during Miocene and Pliocene time. This condition persisted through the Pleistocene and even into the Recent, and gave rise to a uniformity of lithology and similarity of faunas which render the separation of minor geological horizons difficult. However, the Pleistocene, Pliocene, Miocene, and Oligocene have been recognized definitely, and the approximate contacts between them have been determined. The West Columbia dome is the only other known to us where this nearly continuous marine condition of the Miocene and Pliocene is even closely approximated. Other domes show evidence, usually, of only one or two marine incursions during the Miocene. Five and possibly more are found at Stratton Ridge.

Cuttings and cores from the following wells have been the source of data on the nature of the underlying sediments: Roxana Petroleum Corporation's Seaburn Nos. 1, 2, 3, and 4, which give sections of the Pleistocene, Pliocene, and top of the Miocene; Freeport Sulphur Company's Tolar and Dannenbaum Nos. 9, 10, 11, and 12, and Seaburn Nos. 1, 2, and 3, all below 2,000 feet, give Miocene

[1] Private report by William Kennedy.

and Oligocene sections; Humble Company's Brock Nos. 1 and 2, Shea-Storrie No. 1, Seaburn B-1 and No. 6 give sections of the Pliocene and Miocene; a few samples from the Castell Oil Company's Storrie No. 1 give a section of part of the Pliocene.

The information regarding the formations encountered in the above wells permits deductions as to the attitude of the beds surrounding the salt core. The facts resulting from this study are set forth below, and the interpretation of these facts is shown on the accompanying cross-sections in Figures 3 and 5.

The contact between the Pliocene and Miocene beds is recognized in the Roxana's Seaburn 1, 2, and 3 at the following depths: No. 1 at 1,469 feet, No. 2 at 1,506 feet, No. 3 at 1,750 feet. No. 4 did not encounter any Miocene, and the lower part of the Pliocene is missing. In the Humble's No. 1 Shea-Storrie, the Pliocene-Miocene contact is placed at about 1,800 feet, and in their Seaburn B-1, at about 1,540 feet. The Humble's No. 2 Brock entered beds of Miocene age between 1,300 and 1,600 feet, but the contact cannot be placed closer, as no samples were taken in this interval. In Brock No. 1, the Miocene beds are first encountered at about 970 feet.

In the Humble's Seaburn No. 6, Miocene was first encountered at about 1,500 feet. The Castell Oil Company's Storrie well at the crest of the ridge found no Miocene sediments; in fact, the lowest part of the Pliocene seems to be missing.

In studying the samples from the Roxana wells, it is found that three divisions may be made within the Pliocene, largely on the basis of lithology. These three divisions are shown on Section A–A[1] in Figure 3, and are more fully described in the paragraph on "Stratigraphy." In the Castell Oil Company's No. 1 Storrie, on the crest of the ridge, from which only a few samples were available for study, it appears that probably only the upper zone is present. In the Roxana No. 4, on the west side of the ridge (not shown on section), the lowest zone of the Pliocene was not found. The well entered the gypsum cap at 1,003 feet. The lithological divisions of the Pliocene recognized in the Roxana well samples were also observed in the Humble's Seaburn B-1, and show about the same thickness as in the Roxana wells except that the lowest member is somewhat thinned. In the Humble's Brock No. 1, only the upper Pliocene is thought to be present and seems to overlie the upper Miocene at 970 feet.

The upper Miocene and the lower Pliocene sediments apparently do not pass over the top of the dome, but lap up around the sides. The upper portion of the Pliocene passes over the top of the salt core. The Pliocene beds, in the vicinity of the Roxana wells at least, show comparatively little uplift, possibly about 200 feet.

Nothing is known of the Miocene-Oligocene contact and the attitude of the lower formations save at the northeast end of the ridge. Samples studied from six of the wells in this group show definitely that they were drilled into the Oligocene. These wells are the Freeport Sulphur Company's Tolar and Dannenbaum 9 and 11, Seaburn 1 and 3, and Cannan's Boggs No. 1 and No. 2. It is also probable that the Empire's Wilson No. 1, 4,671 feet in depth, penetrated

the Oligocene, but definite information is lacking. The location of these closely grouped wells is shown on the large-scale map in Figure 4.

Within the Miocene, the three divisions designated upper, middle, and lower are recognized on the basis of foraminiferal and lithological changes. Three divisions are also recognized in the Oligocene.

No samples were available for study from Tolar and Dannenbaum No. 8. In No. 10, the first samples received were from 1,235 feet and were in the upper zone of the Miocene. Middle Miocene beds were recognized from about 1,400 to 1,850 feet, and the lower Miocene was found from 1,850 feet, the top of the cap at 2,617 feet.

Consecutive samples were received from Tolar and Dannenbaum No. 9 beginning at 3,000 feet and were found to be lower Miocene to 4,005 feet.

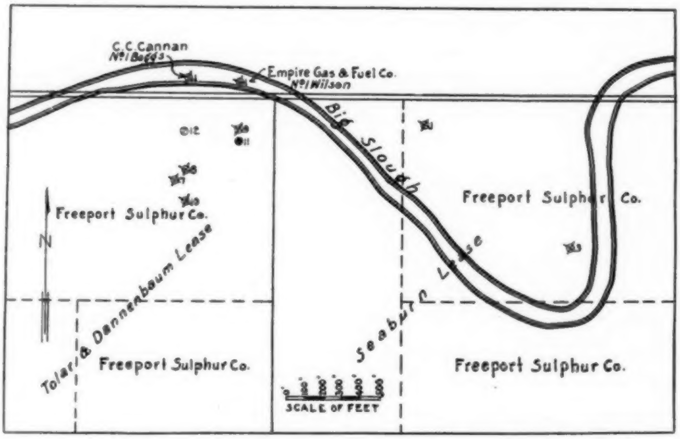


FIG. 4.—Map showing location of wells at northeast end of Stratton Ridge

Oligocene continued to the bottom of the hole at 4,364 feet. The lowest Oligocene or *Marginulina* zone was identified at about 4,350 feet. The sand from which this well produced for a short time (4,344–4,364 feet) evidently belongs in the lowest Oligocene.

In a few samples from Tolar and Dannenbaum No. 11 taken at about 3,500 feet, lower Miocene Foraminifera were found. Samples from about 4,050 feet were well down in the Oligocene, and the lowest or *Marginulina* zone was recognized at 4,140 feet. Oligocene continued to 4,350 feet, where the well entered a non-fossiliferous zone of indeterminate age. The production from this well is obtained at 4,249–4,386 feet in the lowest Oligocene.

Our samples from the Freeport Sulphur Company's Seaburn No. 1 began at about 3,100 feet. Lower Miocene was encountered to 4,051 feet, and Oligo-

cene to about 4,650 feet, the *Marginulina* zone being recognized at about 4,500 feet. Below 4,650 feet there is a non-fossiliferous zone similar to that found in Tolar and Dannenbaum No. 11. Salt was encountered at 4,765 feet.

Seaburn No. 3 drilled in middle Miocene from about 2,300 to 3,200 feet and in lower Miocene to about 3,950 feet. From this point the Oligocene was found to 4,416 feet, where the samples ended (total depth 4,442 feet). The *Marginulina* zone of the Oligocene was recognized in this well at 4,350 feet. The top of the Oligocene at 3,950 is the highest point at which this formation has been identified on this dome. It may be higher than this in other wells from which samples were not received.[1]

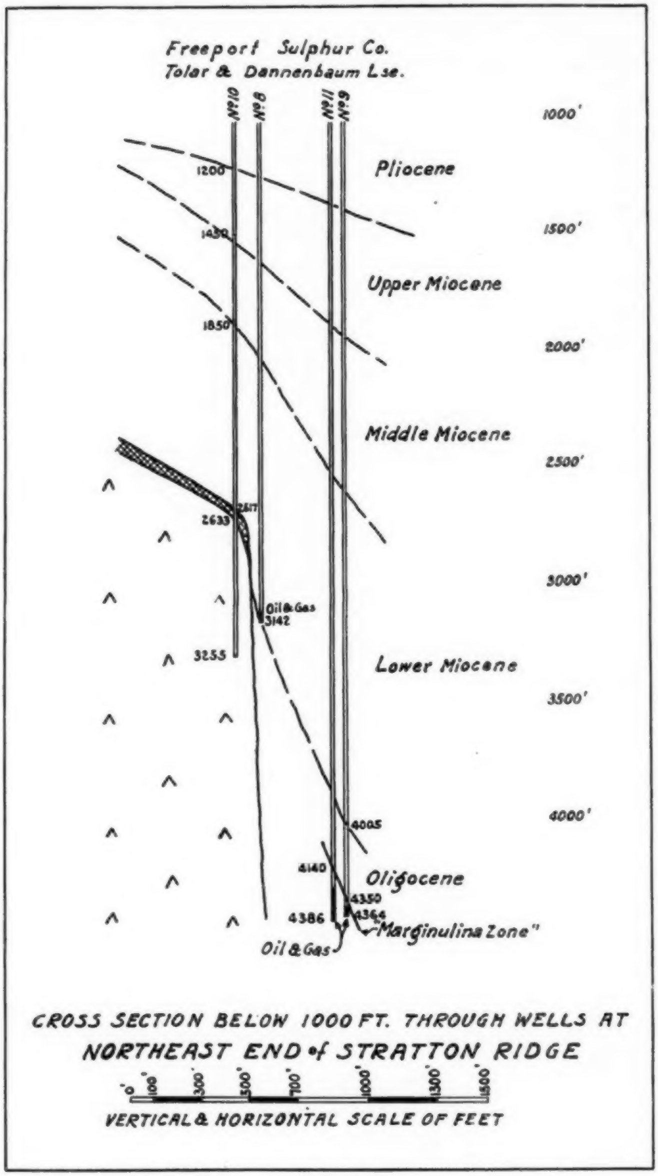
Samples from Boggs No. 1 taken at 4,200 feet are of Oligocene age. The *Marginulina* zone was recognized at 4,475 feet. Figure 5 is a cross-section on a horizontal and vertical scale of 500 feet to the inch drawn through the Freeport's Tolar and Dannenbaum Nos. 10, 8, 11, and 9, and shows the probable relations of the formations to the salt core at the northeast end of the ridge. The *Marginulina* zone in the lowest Oligocene is found to be 210 feet higher in No. 11 than in No. 9, and a horizon picked up at 2,422 feet in No. 10 may possibly be correlated with the formation found in No. 9 at 3,196 feet. This would indicate steeply tilted formations close to the salt core and a considerable dragging up of the lower beds alongside the salt. It seems even possible that the oil and gas encountered at 3,082–3,142 feet in Tolar and Dannenbaum No. 8 may be from upthrust Oligocene beds.

In Seaburn No. 3, the Oligocene is found to be from 100 to 150 feet higher than in Seaburn No. 1, due possibly to the effect of the salt ridge plunging away from the main core in this area.

No Oligocene was encountered in any of the deep wells drilled by the Humble on the east side of the ridge, nor in the Shea-Storrie (total depth 4,086 feet) on the northwest side of the ridge. Samples from this well at 4,015 feet, as determined by Miss Ellisor of the Humble Company, are shown to be Miocene in age.

An interesting find is reported by Miss Ellisor from the Humble's Brock No. 2, on the west side of the ridge (Fig. 3, Section C–C[1]). At 2,040 feet, reworked Oligocene Foraminifera were found in marine Miocene sediments, and again at 2,673 feet, reworked fragments of limestone carrying well-preserved Oligocene Foraminifera appeared. Beds of Miocene age occurred below. The presence of these well-preserved Oligocene fossils and fragments of limestone doubtless indicates that the Oligocene outcropped close at hand during Miocene time and that the fragments were washed out into the Miocene sea. We may also infer from the occurrence of these fossils that uplift at Stratton Ridge was going on in the Miocene, that the uplift of the Oligocene was as great or possibly greater than is indicated on the northeast side of the dome, and that the salt

[1] The "*Discorbis* zone" of the Vicksburg has recently been recognized in Tolar and Dannenbaum No. 12 at 3,713 feet.



Freeport Sulphur Co.
Tolar & Dannenbaum Lse.
Nº10
Nº8
Nº11
Nº9
1000'
1500'
2000'
2500'
3000'
3500'
4000'
Pliocene
Upper Miocene
Middle Miocene
Lower Miocene
Oligocene
"Marginulina Zone"
1200
1450
1850
2617
2633
Oil & Gas
3142
3255
4005
4140
4350
4364
4386
Oil & Gas
CROSS SECTION BELOW 1000 FT. THROUGH WELLS AT
NORTHEAST END of STRATTON RIDGE
0
100
300
500
700
1000
1300
1500
VERTICAL & HORIZONTAL SCALE OF FEET

Fig. 5

core may show a much steeper west side than that indicated in Section C–C[1] of Figure 3.

STRATIGRAPHY

Study of the samples from the several wells mentioned above affords basis for a generalized description of the formations from the Pleistocene to the Oligocene, and for designation of characteristic features of these sediments at Stratton Ridge.

Beds older than upper Miocene have not been penetrated, unfortunately, by wells from which continuous samples beginning at the surface are available, and samples from beds above the lower part of the Miocene have not been secured from wells which went into the lower Miocene or older formations. Furthermore, the wells which give the best record of the Pliocene and upper Miocene, the Roxana wells, are situated on the southeast side of the dome, while those from which most information regarding the older beds is gained, the Freeport wells, are located on the northeast side of the dome. The upper section from the Roxana wells must therefore be combined with the lower part of the section from the Freeport wells in order to get a complete record of the formations encountered in drilling around this dome. The most complete section of the lower formations is given in the Freeport's Seaburn No. 3, which is here taken as typical. In this well samples were obtained from depths between 1,484 and 1,525 feet which are identical in lithology and fauna with the upper Miocene section found in the Roxana's Seaburn wells.

GENERALIZED SECTION AT STRATTON RIDGE[1]

Recent and Pleistocene

Gray and yellow sand and sandy clay which contain fragments of oyster shells and a few Foraminifera, identical with forms found on Galveston Beach at the present time. These include *Rotalia beccarii* Linn., *R. beccarii* var. *galvestonensis* n. var.,*[2] *Nonionina* cf. *depressula* Walker and Jacob, *Polystomella galvestonensis* n. sp.*. The base of the Pleistocene is marked by a bed of nonfossiliferous sand, generally logged as a water sand, about 30 feet thick and consisting of well-worn, uneven-grained, moderately coarse, tan-colored sand. The thickness of the Pleistocene and Recent deposits is 100 to 200 feet.

[1] See also graphic section, Fig. 6.

[2] Manuscript new species in this paper are designated by *.

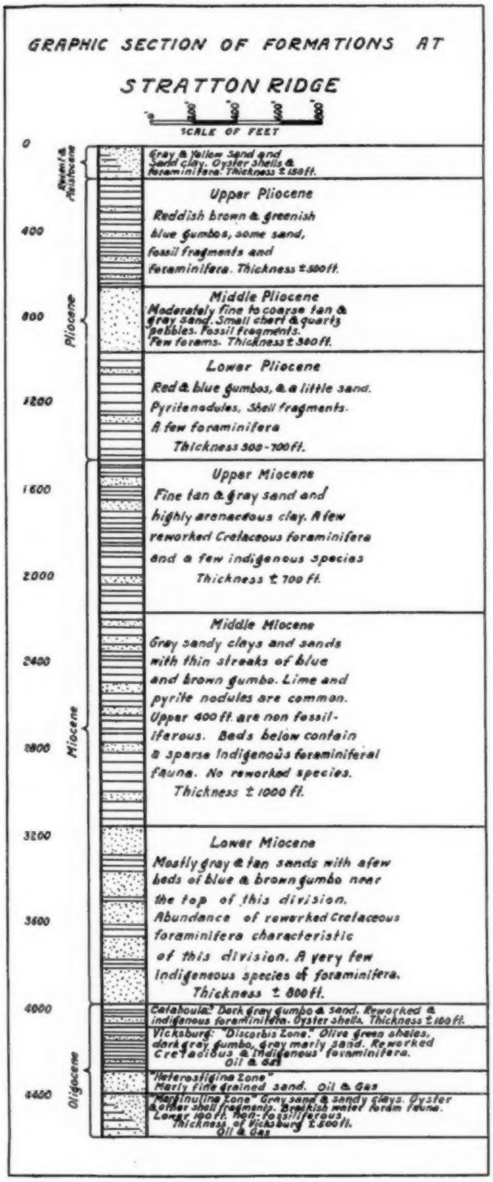

GRAPHIC SECTION OF FORMATIONS AT
STRATTON RIDGE
SCALE OF FEET
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
4400
Pliocene
Miocene
Oligocene
Gray & Yellow Sand and Sand clay. Oyster shells & foraminifera. Thickness ± 150 ft.
Upper Pliocene
Reddish brown & greenish blue gumbos, some sand, fossil fragments and foraminifera. Thickness ± 500 ft.
Middle Pliocene
Moderately fine to coarse tan & gray sand. Small chert & quartz pebbles. Fossil fragments. Few forams. Thickness ± 300 ft.
Lower Pliocene
Red & blue gumbos, & a little sand. Pyritenodules, Shell fragments. A few foraminifera
Thickness 300-700 ft.
Upper Miocene
Fine tan & gray sand and highly arenaceous clay. A few reworked Cretaceous foraminifera and a few indigenous species
Thickness ± 700 ft.
Middle Miocene
Gray sandy clays and sands with thin streaks of blue and brown gumbo. Lime and pyrite nodules are common. Upper 400 ft. are non fossiliferous. Beds below contain a sparse indigenous foraminiferal fauna. No reworked species.
Thickness ± 1000 ft.
Lower Miocene
Mostly gray & tan sands with a few beds of blue & brown gumbo near the top of this division. Abundance of reworked Cretaceous foraminifera characteristic of this division. A very few indigeneous species of foraminifera.
Thickness ± 800 ft.
Catahoula: Dark gray gumbo & sand. Reworked & indigenous foraminifera. Oyster shells. Thickness ± 100 ft.
Vicksburg: "Discorbis Zone." Olive green shales, dark gray gumbo, gray marly sand. Reworked Cretacious & Indigenous foraminifera.
Oil & Gas
"Heterostigina Zone"
Marly fine grained sand. Oil & Gas
Zone" Gray sand & sandy clays. Oyster shell fragments. water foram fauna.
Lower 100 ft. non-fossiliferous.
Thickness of Vicksburg ± 500 ft.
Oil & Gas

FIG. 6

Pliocene

On the basis of certain constant lithological characters, we have divided the Pliocene into three divisions, designated upper, middle, and lower, respectively.

Upper division.—Reddish-brown and greenish-blue gumbos are the characteristic materials composing this part of the Pliocene. Nearly all of the cuttings when washed contain a small amount of sand, some fossil fragments, and Foraminifera. *Chara* fruit cases are also occasionally found. The foraminiferal fauna is similar to that of the Pleistocene, but the species are more varied and a few of the varieties are apparently confined to the Pliocene. The majority of the species continue into the younger period, as would be expected. The Foraminifera and other fossils found in this division are forms which indicate a shallow marine condition of deposition. The most common Foraminifera present are: *Rotalia beccarii* Linn., *Polystomella galvestonensis* n. sp.,* *Rotalia beccarii* Linn. var. *galvestonensis*,* *Polystomella striato-punctata* (Fichtel and Moll) Parker and Jones, *Textularia* n. sp., *Polystomella craticulata* (Fichtel and Moll var.). Ostracod carapaces, *Rangia cuneata*, and a number of other pelecypods and gastropods are also present in a few of the samples. The thickness of this division is about 500 feet.

Middle division.—Moderately fine to coarse, tan and gray sands form the major portion of the materials of this Pliocene division. The sands are sometimes indurated, and nodules of small pyrite crystals and chalky lime are common. Small chert and quartz pebbles are also characteristic, and shell fragments continue as in the upper division. The Foraminifera are also the same as those found in the higher portion of the section, but are fewer in number and less varied as to species than in the upper beds. The thickness of this division is about 300 feet.

Lower division.—Red and blue gumbos are the dominant materials in the lower part of the Pliocene. These gumbos contain a varying amount of fine sand which is generally angular, some nodules of pyrite, many shell fragments, a few small, well-preserved shells, and a few Foraminifera, as in the division just above. *Chara* seeds are also found in these beds. The thickness of this division is 500 feet or more.

In the Pliocene beds encountered in the Associated Oil Company's Perry No. 1, there was found an *Orbitulina* of peculiar conical form, common to and characteristic of the Walnut clays.[1] This is interesting in that it may shed some light on the source of the material making up these sediments.

Miocene

The upper Miocene is found in the Roxana's Seaburn Nos. 1, 2, and 3. Although the Miocene and Pliocene formations on this dome are particularly difficult to divide because of the almost continuous conditions of shallow marine deposition which existed at this time, we are reasonably confident of the line

[1] The Walnut clays are a member of the Fredericksburg group of the lower Cretaceous.

of their separation, which has been established on both faunal and lithological grounds found to be constant in the wells mentioned. So far as we can ascertain, in one of the Roxana wells is the middle or lower Miocene present as it is found on the northeast side of the dome, where we are able to study these formations in some of the Freeport Sulphur Company's wells.

Upper division.—An oyster-shell reef marks the upper extension of these beds. Heavy oyster-shell fragments also occur frequently and abundantly throughout the samples submitted from this division. Lithologically, the upper part of the Miocene is composed mainly of fine sands and highly arenaceous clays, some of which are micaceous. The sands are gray and tan in color, and the grains are generally angular. Nodules of pyrite and lime occur occasionally. Selenite crystals were common in the sands from this division in the Roxana Seaburn No. 3. A few reworked Cretaceous Foraminifera and a number of indigenous species occur in the samples. Some of the more common species present are: *Rotalia beccarii* Linn. var. (apparently confined to the Miocene), *Polystomella strattoni* n. sp.,* *Truncatulina* cf. *americana* Cush. var., *Textularia strattoni* n. sp.,* *Quinqueloculina* (several species). The thickness of the upper Miocene as found in the Roxana wells varies from 300 to 700 feet according to position on the dome.

Middle division.—Lithologically, the middle part of the Miocene is composed of beds of gray, sandy clays and sands with thin streaks of blue and brown gumbo. These beds contain no marine fossils of any kind. Lime and pyrite nodules are common. Beds of this description occupy the upper 400 feet of the middle Miocene as exposed in the Freeport's Seaburn No. 3. They are followed by a series of sediments that are largely non-fossiliferous, but include a few thin layers that contain some indigenous species of Foraminifera, Miocene varieties of *Rotalia beccarii* and *Polystomella*. Dark-blue and greenish-blue gumbos form the upper portion of these beds, and gray gumbos and packed sands the lower postion. Oyster-shell fragments were noted in one sample, and a small amount of glauconite in another. Because of the similarity of lithologic character, sparseness of fauna, and total absence of secondary foraminifers, we have included the above-described beds in the middle Miocene, giving that division a thickness of about 1,000 feet in this well. Throughout this division, the conditions of deposition were only rarely favorable to the existence of marine fossil faunas, and the source from which the sands were derived apparently did not include beds containing an abundance of Cretaceous Foraminifera such as form a part of the Miocene sediments in the Gulf Coast region.

In the Boggs No. 1, a horse tooth was secured from beds presumably of this division. The following determination was made by Dr. Chester Stock of the University of California: "An upper tooth of a horse which appears to me to represent some of the members of the *Merychippus* group. It is a long-crowned tooth, unique in its small size, but seems to possess all the general characteristics held by *Merychippus*. This genus is characteristic of the Miocene from a little below the middle of the period to the top. This particular specimen is compara-

ble in size to some of the teeth of *Merychippus* that Dr. Buwalda collected in the Tehachapi and which belong apparently to the lower stage of the middle Miocene."

Lower division.—We believe that the introduction of the secondary material just mentioned above marks a change in the source of depositional material and possibly depositional conditions as well, and therefore place the top of this division at the first appearance of these forms below the non-fossiliferous zone. The divisions made here are rather arbitrary, and further study may prove that they are not so constant as we now suppose. The major portion of this division of the Miocene is composed of gray- and tan-colored sands. There are a few beds of blue, brown, and red gumbos, the major portion of which occur near the top of this division. The sand grains are generally very fine and usually even in size. Lime nodules and *Chara* fruit cases are found. Secondary Foraminifera occur abundantly throughout these beds, and a few indigenous forms are found at rare intervals. The thickness of this division in the Seaburn No. 3 is about 800 feet.

Oligocene

Catahoula?—At the base of the lower Miocene and for a few hundred feet directly overlying the Vicksburg Oligocene, we note a series of dark-gray gumbos and sands in each well from which we have good cores. These beds contain secondary Foraminifera and indigenous species like those mentioned above, some beds of oyster shells, and, as we approach the contact with the Vicksburg, a few species of Foraminifera common to the lower formation gradually appear, i.e., *Cristellaria*, *Orbitolina*, *Quinqueloculina*, *Nonionina*, and an occasional *Pulvinulina texana*.* There are two explanations for this condition: (1) either the Catahoula was entirely eroded before the deposition of lower Miocene sediments and the Vicksburg forms found here were reworked into these beds in lower Miocene times, or (2) these beds represent the gradual shallowing of the sea around this dome during Catahoula time while non-marine sediments were being deposited in the more northern area, there being consequently no sharp break between the definitely recognized Vicksburg below and the Miocene deposits above. We incline toward the latter view because (1) these beds are lithologically similar to the Vicksburg on this dome; (2) the species of Foraminifera common to both the true Vicksburg and this series of beds in question, instead of being worn species of abundant and heavy-shelled Vicksburg forms, as one would expect if they were reworked, are, on the contrary, fragile forms common but not dominant in the Vicksburg, and are also genera frequently found elsewhere in sandy, near-shore deposits. To be sure, reworked Vicksburg Foraminifera are found in Miocene sediments in the Humble's Brock No. 2 (see above), but the Miocene there is true marine Miocene, and not at all comparable to the beds here in question.

The thickness of this zone varies, but seems to average about 100 feet.

Vicksburg.—The presence of this formation was unknown in Texas until

three years ago. It is now a well-known and easily recognized feature of the Gulf Coastal dome stratigraphy. In a recent paper by Applin, Ellisor, and Kniker[1] the Vicksburg has been subdivided into three parts on the basis of certain fairly constant faunal groups which take their names from the genera of Foraminifera found to be characteristic or dominant in each. These are the upper or *Discorbis* zone, middle or *Heterostegina* zone, and the lower or *Marginulina* zone.

Upper or *Discorbis* zone. Lithologically, this division of the Vicksburg here consists of a few upper beds of dark, olive-green shales followed below by dark-gray gumbos and greenish-gray, very fine-grained, marly sands. Nearly all the samples contain many indigenous species of Foraminifera and a few reworked Cretaceous forms. The *Discorbis* fauna is represented by very abundant and varied forms. This condition is true of Hoskins Mound as well, while on the majority of the coastal domes the number of species and individuals in the upper zone is not large, and the forms as a whole are not so well developed as in the older beds. This faunal assemblage is an index to conditions of deposition. Since nearly all the Foraminifera present are bottom-living forms, they may indicate that slightly deeper or quieter water conditions existed here than over the major portion of this area. The most common and abundant species in this zone here are:

Discorbis cf. *bertheloti* Cushman (form as figured by Cushman in *Prof. Paper 129E*, Pl. 32, Fig. 7)
Nonionina pratti n. sp.*
Polystomella striato-punctata (Fichtel and Moll) Parker and Jones n. var.
Polystomella macella Fichtel and Moll n. var. *dumblei** (without the keel)
Polystomella crispa (Linnaeus) Lamarck var. *seaburni* n. var.* (without a keel)
Polystomella texana n. sp.*
Pulvinulina texana n. sp.*
Pulvinulina texana n. sp. var. *strattoni* n. var.*
Rotalia beccarii Linnaeus
Cristellaria vicksburgensis Cushman
Cristellaria cf. *calcar* Linnaeus (as figured by Flint but without the spines)
Globigerina rubra d'Orbigny
Siphonina n. sp.
Textularia tolari n. sp.*
Nonionina scapha (Fichtel and Moll) Parker and Jones n. var (as figured by Cushman, *Prof. Paper 129E*, Pl. 23, Fig. 7)
Ehrenbergina glabrata Cushman
Quinqueloculina crassa d'Orbigny
Quinqueloculina glabrata Cushman
Textularia cf. *subhauerii* Cushman

Middle or *Heterostegina* zone. This division of the Vicksburg at West

[1] "The Subsurface Stratigraphy of the Costal Plain of Texas and Louisiana," by Esther Richards Applin, Alva Ellisor, and Hedwig Kniker.

Columbia and Damon Mound is a highly fossiliferous limestone, but is here represented by a thin bed of marly, fine-grained sand which does not contain the *Heterostegina* which gives the division its name, but carries many specimens of *Amphistegina* n. sp. and other forms characteristic of this zone. The lower portion of this middle zone lacks the *Amphistegina* mentioned above, and shows a return of a fauna very similar to that of the *Discorbis* zone above. The most common and abundant species of Foraminifera present in this zone are:

Uvigerina byramensis Cushman
Amphistegina lessoni var. *texana* n. var.*
Pulvinulina texana n. sp.*
Cristellaria orbicularis d'Orbigny
Cristellaria rotulata Lamarck var.
Globigerina bulloides d'Orbigny
Globigerina conglobata Brady
Rotalia beccarii Linnaeus
Polymorphina byramensis Cushman
Cristellaria vicksburgensis Cushman
Truncatulina lobulata (Walker and Jacob) d'Orbigny
Truncatulina cf. *americana* (as figured by Cushman, *Prof. Paper 129E*, Pl. 20, Fig. 7)
Rotalia vicksburgensis Cushman
Polystomella crispa (Linnaeus) Lamarck var. *seaburni*. n. var.*
Textularia n. sp. (nearest to *T. hockleyi** of the Texas Jackson)
Quinqueloculina, several species

Lower or *Marginulina* zone. The lower part of the Vicksburg at Stratton Ridge differs markedly from the lower or *Marginulina* zone at West Columbia, Goose Creek, Damon Mound, and Pierce Junction. The genera and species of Foraminifera and the character of the sediments found on these other domes in this zone suggest that quiet and comparatively deep waters prevailed there. At Stratton Ridge, on the other hand, the lower zone of the Vicksburg is made up of a series of sands and sandy clays that frequently carry oyster and other shell fragments, and the Foraminifera present are only calcareous pseudomorphs of a variety of *Rotalia beccarii*, a form characteristic of shore and brackish-water deposits. One or two specimens of *Quinqueloculina* sp. which also occur in near-shore as well as deep-water deposits have been found. Beds belonging to this zone have been penetrated for about 200 feet, and it has been found that the foraminifera mentioned above occur only in the upper 100 feet. The lower beds are non-fossiliferous. No formation older than Vicksburg Oligocene has thus far been identified on this dome.

The total thickness of the Vicksburg Oligocene as we know it at Stratton Ridge is about 500 feet.

MACROSCOPIC FOSSILS

The following list of macroscopic fossils has been prepared from forms identified in samples received from various wells drilled at Stratton Ridge.

Castell Oil Company's Storrie No. 1

Feet

870–872....*Arca*, worn; in outline resembles *A. labiata* var., of Galveston deep well, upper Miocene; *Arca alcima* from Caloosahatchie beds has somewhat similar outline.

872–874....*Bittuim* sp., broken; may be *B. galvestonensis* Harris, of Galveston well, upper Miocene.
Phacoides crenulatus
Corbula sp., broken
Cerithium, fragment; may be *C. galvestonensis* Harris.

Freeport Sulphur Company's Seaburn No. 1

3,121........*Mactra lateralis*, Say, Galveston deep well 300–2,920
Mactra quadricentennialis Harris, Galveston deep well 2,123–2,873
Pecten sp.

3,241 ....*Nassa trivitatata* Say, Miocene and Pliocene Maryland
Olivella fragments
Turbinella sp. worn fragment
Pleurotoma cf. *calvertensis* Clark, Miocene of Maryland
Cylichna bidentata var. *galvestonensis* Harris, Galveston deep well 2,600–2,733
Chione cancellata fragment, Linné, Galveston deep well 1,550–2,871
Arca incongrua Say fragment, Galveston deep well 2,443–2,920
Mactra lateralis Say
Mactra quadricentennialis Harris
Strombina sp., not determined
Pecten fragment

3,245........*Arca* fragment
Chione cancellata fragment Linné
Natica cf. *eminuloides* Gabb, Galveston deep well 2,465–2,733
Corbula resembling most closely *C. seminula* Dall, Miocene
Mactra fragments
Terebra close to *gatunensis* Toula, middle and upper Miocene

3,352........*Chione*, middle Miocene form, fragment
Balanus sp.
Arca transversa Say, var. *busana* Harris, Galveston deep well, surface to 2,920
Pecten fragment

3,445........*Nassa acuta* Say var., Galveston deep well 440–2,871
Olivella fragment
Natica sp. fragment
Arca sp. fragment

Natica eminuloides Gabb, young
Mactra quadricentennialis, Harris
Dreissensia sp.

3,670–3,739. . *Pecten, Ostrea, Leda* fragments
3,810–3,862. . *Terebra curvilineata* Dall, Miocene
4,051–4,060. . *Chione, Leda, Dentalium* fragments, and fish teeth
4,060–4,177. . *Leda* and *Natica* sp. fragments
Nassa sp. like sp. in Tolar and Dannenbaum at 4,241 feet cf.
Nassa trivatiatoides Whitfield
4,470–4,496. . Fragment of a small *Cerithiopsis?*
4,554–4,571. . Fragments of shells, chiefly *Ostrea*
4,714–4,720. . Fragments of *Ostrea* shells

Freeport Sulphur Company's Tolar and Dannenbaum No. 9

3,234. . . . . *Mulinea lateralis* Say, like specimens from the Galveston deep well, 300–2,920, Miocene to Recent.
3,262. . . . . Shell fragments of *Ostrea, Balanus, Pecten, Chione cancellata?* and other undetermined bivalves.
3,312. . . . . Fragments of *Chione cancellata* Linné, Galveston deep well 1,550–2,871. Geologic range: upper Miocene of Galveston deep well and of South Carolina; Pliocene of Caloosahatchie; Pleistocene of North Carolina and the West Indies.
Mulinea lateralis Say
Balanus sp. undt.
Carcharias sp.
3,818. . . . . *Chione cancellata* Linné
Poorly preserved gastropod, possibly *Turritella* sp.
3,941. . . . . *Natica* sp.
Pecten sp. undt.
Corbula inaequalis Dall, Miocene
Arca sp. undt.
Balanus sp.
Chione like form from the Oak Grove, middle Miocene of Florida
Nassa sp. undt.
Leda sp. undt.
Glycimeris sp. undt.
Otoliths of teleost fishes
Carcharias sp.
4,078. . . . . *Chione* middle Miocene form[1]
Cerithiopsis like form from Oak Grove, middle Miocene of Florida

[1] Certain macroscopic Miocene fossils appear in this list below the depth at which the top of the Oligocene has been placed. In each case these fossils were found in cuttings and were undoubtedly washed down the hole. Cores showed only Oligocene forms with no Miocene present.

	Balanus sp.
	Ostrea sp.
	Leda sp.
	Arca sp.
4,087........	*Chione* as above
	Natica sp., broken
	Oliva aff. reticularis Lam, Galveston deep well 2,158–2,920
	Mulinea sp., broken
	Otoliths of teleost fishes
4,115........	*Cupularia umbellata*, lower Miocene to Recent, especially characteristic of the lower Miocene of the West Indies
	Chione, as above
	Nassa, like species from the Oak Grove, middle Miocene of Florida
	Arca sp. fragment
	Cylichna sp.
	Mulinea lateralis? Say, broken
4,241–4,250..	*Chione*, as above
	Balanus sp.
	Pecten sp.
	Nassa sp., bearing a close resemblance to the form *Tritia trivitatoides* in the Miocene of New Jersey, but differing from it in a number of details
4,276–4,338..	Fragments of *Chione*, middle Miocene form
	Bryozoan, probably belonging to the genus *Semihaswellia*, species not described.

Humble Oil and Refining Company's Seaburn B-1

910–925....	Fragment of *Eulima?* sp.
	Planorbis ophis? Dall cf. *Teinostoma*, Miocene of Maryl nd; brackish-water Pliocene of Louisiana; cf. Fort Thom,son species.
	Two worn and broken specimens of coiled shell with low spine
1,100–1,137..	*Nassa acuta* Say, upper Miocene to Pleistocene in Galveston deep well
1,194–1,224..	*Nassa acuta* Say
	Arca (*Plio* sp?) does not seem to be *A. ponderosa*
1,486–1,494..	*Nassa? acuta* Say, broken specimen
	Young of *Nassa acuta* or *Phos;* same form as at 547–557 in S. No. 1 Roxana, and at 1,500 in Perry No. 1
	Low-spined smooth gastropod
1,567–1,582..	*Phos* sp., same form as at 1,500 in Perry No. 1
1,646–1,661..	*Mulinea sapotilla* Dall, brackish-water Pliocene of Louisiana
	Phacoides crenulatus Conrad

1,661–1,670. . *Mulinea lateralis*, young
Paludestrina aff. aldrichi Dall, brackish-water Pliocene of Louisiana

Roxana Petroleum Company's Seaburn No. 1

449–487. . . . *Paludestrina* sp. cf. *Syrnola caloosaensis* Dall, upper Miocene—Pliocene of Florida; not a *Syrnola*
Paludestrina cf. *aldrichi* Dall fragment, brackish-water Pliocene from near Alexandria, Louisiana
Paludestrina? n. sp.? anterior portion more angulated than any species from brackish-water Pliocene of Louisiana
Spisula cf. *subparilis*, Conrad, Tertiary of Florida, upper Miocene of Maryland

547–557. . . . Fish tooth?
Phos? sp. cf. form in Avoca well called young of *Nassa acuta;* also occurs at 1,500 in Perry No. 1.

Roxana Petroleum Company's Seaburn No. 2

382–413. . . . *Rangia* sp., broken.
Mulinea, probably *lateralis*, two broken specimens; this species ranges from Miocene to Recent.

Roxana Petroleum Company's Seaburn No. 3

409–530. . . . *Nassa acuta* Say; Harris gives the range as upper Miocene to Pleistocene.
Scala cf. *sayana* Dall, from the upper Miocene of Maryland; Dall lists this species from the Pliocene of Caloosahatchie and the Recent from Texas to Key West.

1,557–1,580. . *Mulinea* sp., broken.
Corbula sp., very close to species from Oak Grove and Galveston well (*C swiftiana?*); Harris gives range of the Galveston well species as upper Miocene to Pleistocene; cf. *C. sphenia* (Chapola).
Phacoides crenulatus Conrad; Harris gives the range of this species in the Galveston well species as upper Miocene, but the Pleistocene species from West Palm Beach is the same.
Gemma n. sp. cf. *G. purpurea* var. *totteni* Dall

1,633–1,644. . *Mulinea* sp., broken

1,770–1,796. . *Mulinea* cf. *sapotilla* Dall, from brackish-water Pliocene of Louisiana, Bryozoans, *Membranopora*, possibly *M. flabellata*, upper Miocene to Recent

1,899–1,930. . *Corbula* sp. from 1,557 to 1,580, range upper Miocene to Pleistocene

2,185–2,189. . *Corbula* sp., broken; does not appear to be the same as *Corbula* at 1,557 or 1,899.

GEOLOGIC HISTORY OF THE DOME

Paleontological study has shown that during the earliest part of Oligocene time the lithological and faunal characteristics of the sediments at West Columbia, Goose Creek, Damon Mound, and Pierce Junction suggest prevailing quiet and comparatively deep waters. At Stratton Ridge, to the east and south of these domes, the lowest Oligocene sediments are lithologically and faunally characteristic of near-shore and brackish-water conditions. This suggests that perhaps some uplift took place in this region during or just prior to the earliest Oligocene.

The top of the salt core at Stratton Ridge is about 3,000 feet above the original position of the now upwarded Oligocene, and the sediments of this and the Miocene periods are shown to be sharply upthrust and steeply tilted close to the sides of the salt mass, at least on the northeast side of the dome, where we have the most complete information. The Pliocene sediments overlie the Miocene beds unconformably near the salt core. No Miocene sediments pass over the top of the salt, nor do the lowest Pliocene. The Miocene-Pliocene contact shows an uplift of about 300 feet in the Roxana Seaburn Nos. 1, 2, and 3, while the overlying Pliocene beds show less and apparently lie nearly flat across the top of the salt. It therefore seems probable that the intrusion of the salt and the period of maximum deformation came between the Oligocene and early Pliocene. Some minor upthrust of the salt evidently has taken place since the Pliocene.

OIL AND GAS

The indications which led to drilling at Stratton Ridge were gas seeps in a water well near Stubblefield Lake, and the topographic expression of the salt dome.

Shows of oil and gas were encountered in thin sands above the gypsum anhydrite cap in some of the Freeport Sulphur Company's wells drilled on the top of the salt. The Castell Oil Company's Storrie No. 1 had a strong gas blow-out at about 750 feet, but the flow was not lasting. There is no record of any showing of oil or gas in the Roxana wells. No commercial production was ever developed on the top of the salt, and the wells drilled there have tested the

cap and the sands above with sufficient thoroughness to prove further prospecting for cap-rock oil useless.

Four of the wells drilled on the northeast side of the dome have encountered good indications of oil in the lateral sands. These wells are the Freeport Sulphur Company's Tolar and Dannenbaum Nos. 8, 9, and 11 and C. C. Cannan's Boggs No. 2. In the Tolar and Dannenbaum No. 8, oil and gas were found at 3,082–3,142 feet. This well was abandoned at the latter depth. In No. 9, the record gives several oil and gas shows between the depths of 3,100 and 4,300 feet. Twenty feet of sand logged from 4,344 to 4,364 feet at the bottom of the hole produced 28° B. oil for a short time and then sanded up. No. 11 had showings of oil from 3,501 to 3,512 feet and pumps about 75 barrels a week from sand and shale at a depth of 4,249–4,386 feet, but the well is not pumped regularly. C. C. Cannan's Boggs No. 2, the latest well to encounter oil, produced 1,500 to 2,000 barrels a day for a few days from a sand found at 4,274–4,285 feet and is now being pumped. Boggs No. 1 reported oil shows at the following depths: 3,196–3,226 feet, 3,550–3,565 feet, and 4,560–4,575 feet.

Shows of oil and gas were found in the Freeport's Tolar and Dannenbaum No. 10 from 2,218 to 2,430 feet and from 2,554 to 2,602 feet. Gas shows in the Freeport's Seaburn No. 1 occurred at depths of about 3,600, 4,050, 4,250, and 4,550 feet. A show of oil and gas was found in this well at 4,697–4,765 feet. In Farish's Seaburn No. 2, oil is reported from 1,920 to 1,950 feet, and gas from 2,115 to 2,150 feet. It is not known whether oil and gas shows were encountered in any of the Humble's wells drilled on this dome; the records do not show any.

Cores from Tolar and Dannenbaum No. 9 at 4,357 and from Tolar and Dannenbaum No. 11 at 4,371 show the sand to be fine, hard, and closely cemented, probably on account of compression of the sediments accompanying the upthrust of the salt mass.

ACKNOWLEDGMENTS

In presenting this paper, the writer wishes to acknowledge his indebtedness to the Freeport Sulphur Company for permission to use the paleontological information obtained from well samples fur-

LIST OF WELLS DRILLED ON THE STRATTON RIDGE SALT DOME

Company	Lease	Well No.	Total Depth Feet	Remarks
Freeport Sulphur Company	Tolar and Dannenbaum	1	1,312	Cap at 1,084 feet. Salt at 1,308 feet
Freeport Sulphur Company	Tolar and Dannenbaum	2	2,102	Cap at 1,212 feet. Salt at 1,316 feet
Freeport Sulphur Company	Tolar and Dannenbaum	3	1,200	Cap at 1,192 feet. Oil show 1,154–1,173 feet
Freeport Sulphur Company	Tolar and Dannenbaum	4	1,326	Cap at 1,238 feet. Salt at 1,319 feet
Freeport Sulphur Company	Tolar and Dannenbaum	5	1,270	Cap at 1,258 feet. Oil show 1,166 feet
Freeport Sulphur Company	Tolar and Dannenbaum	6	1,345	Cap at 1,338 feet. Gas at 1,153 feet
Freeport Sulphur Company	Tolar and Dannenbaum	7	2,475	Junked
Freeport Sulphur Company	Tolar and Dannenbaum	8	3,142	Junked. Oil and gase shows
Freeport Sulphur Company	Tolar and Dannenbaum	9	4,364	Oil sand 4,344–4,364 feet
Freeport Sulphur Company	Tolar and Dannenbaum	10	3,255	Cap at 2,617 feet. Salt at 2,633 feet
Freeport Sulphur Company	Tolar and Dannenbaum	11	4,386	Oil sand 4,249–4,386 feet. Pumps 75 bbls. per week
Freeport Sulphur Company	Tolar and Dannenbaum	12	....	Drilling
Freeport Sulphur Company	Seaburn	1	4,765	Salt at 4,765 feet. Oil and gas shows
Freeport Sulphur Company	Seaburn	2	2,573	Cap at 2,380 feet. Salt at 2,473 feet
Freeport Sulphur Company	Seaburn	3	4,442	
Roxana Petroleum Corporation	Seaburn	1	1,686	Cap at 1,655 feet
Roxana Petroleum Corporation	Seaburn	2	1,955	Cap at 1,851 feet
Roxana Petroleum Corporation	Seaburn	3	2,522	Cap at 2,490 feet
Roxana Petroleum Corporation	Seaburn	4	1,400	Cap at 1,003 feet. Salt at 1,334 feet
Humble Oil and Refining Company	Seaburn	B-1	3,635	
Humble Oil and Refining Company	Seaburn	B-2	1,799	Cap at 1,609 feet. Gas show 1,650–1,655 feet
Humble Oil and Refining Company	Seaburn	B-3	3,204	Junked
Humble Oil and Refining Company	Seaburn	5	1,121	Cap at 1,045 feet
Humble Oil and Refining Company	Seaburn	6	3,610?	
Humble Oil and Refining Company	Seaburn	7	3,458	
Humble Oil and Refining Company	Brock	1	1,471	Cap at 1,302 feet. Salt at 1,311 feet
Humble Oil and Refining Company	Brock	2	2,904	Junked
Humble Oil and Refining Company	Shea-Storrie	1	4,086	
Farish et al.	Tolar and Dannenbaum	1	2,082	
Farish et al.	Seaburn	1	2,094	
Farish et al.	Seaburn	2	2,758	Abandoned in "sandy gyp." Oil and gas show 1,920–1,950 feet and 2,115–2,150 feet

Dannenbaum	Stratton	1	1,058	
Dannenbaum	Stratton	2	854	Gas show 839–842 feet
Castell	Storrie	1	1,314	Cap at 882 feet. Gas blow-out 750 feet
C. C. Cannan	Boggs	1	4,575	Oil and gas shows
C. C. Cannan	Boggs	2	4,287	Oil at 4,274–4,285 feet
Empire Gas and Fuel Company	Wilson	1	4,671	
The Texas Company	Cochran and McClure	1	2,340	Junked
The Texas Company	Cochran and McClure	2	3,100	
Associated Oil Company	H. B. Perry	1	....	Drilling

nished by them, and also for maps, well logs, and other data; to Mr. William Kennedy, consulting geologist for the Freeport Sulphur Company, for much information regarding the general structural aspects of the dome; to the Humble Oil and Refining Company and the Roxana Petroleum Corporation for furnishing samples obtained from several of their wells, and for permission to use the paleontological data obtained from the samples. The writer is particularly indebted to the paleontological department of the Rio Bravo Oil Company for their generous work in preparing the paleontological data used in this report.

OCCURRENCE OF SULPHUR WATERS IN THE GULF COAST OF TEXAS AND LOUISIANA, AND THEIR SIGNIFICANCE IN LOCATING NEW DOMES

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ABSTRACT

Study of chemical analyses of ground waters in the coast region of Texas and Louisiana indicates that in waters from known salt domes there is a wide variation of sulphur content though higher concentration over the salt core is observed in some cases. Several small ground-water areas unrelated to known salt domes have been distinguished where abnormally high sulphur content is found. These sulphur waters appear to result from surface conditions rather than from buried domes.

For several years the Gulf Production Company has been collecting and analyzing samples of waters from the known salt domes throughout the Coastal Belt of Texas and Louisiana. The object of the work was to determine whether or not waters with high mineral content were of local occurrence over the salt cores of domes, and to compare the results obtained with shallow waters from other localities which appeared to be highly mineralized. Approximately one thousand waters have been analyzed in this work. The samples were for the greater part collected by W. M. Wheless, who performed most of the qualitative tests for hydrogen sulphide, and also compared the analyses of the waters from several wildcat prospects with those of salt dome waters. The quantitative analyses were made in the company's research laboratory in Houston, under the direction of F. M. Seibert and H. E. Minor.

The analyses show that the waters of the known domes vary widely in their sulphur content. At Barber's Hill, for example, a well 37 feet deep and another one 380 feet deep showed practically the same amount of sulphates and hydrogen sulphide; a third well, 150 feet deep, was entirely fresh; at North Dayton, the water in a well 200 feet deep showed sulphuretted hydrogen; another one, 34 feet deep, had a high concentration of sulphates; and another, also

34 feet deep, was entirely free of sulphur compounds. At Goose Creek, sulphur waters occur over an area of more than a hundred square miles. At Cow Bayou, in Orange County, waters containing sulphates and hydrogen sulphide are found far beyond the limits of present production with irregular variation in concentration from the surface down to 600 feet. In the case of Barber's Hill, however, where the areal extent of the salt core has been approximately defined, an average of all the analyses gives a higher concentration over the salt core than the analyses of the waters taken off the salt. But even here, samples taken within a mile of the dome contain a greater percentage of sulphates than most of those from the top of the salt. By a process of averaging, a small area of high concentration can be detected over the salt both at Hockley and Damon Mound, but in the case of the other domes, it is impossible to establish the position of the dome from the occurrence of sulphur waters alone.

In the investigation of waters from localities other than salt domes, several small areas were found which are characterized by an abnormally high percentage of both sulphate and sulphuretted hydrogen. In some instances, shallow waters are as highly impregnated with these constituents as any dome waters that have come to our attention; whereas, all the available waters from deeper sands are quite fresh. Actual drilling of several of these prospects has given no evidence that the sulphur content in these waters is due to a buried dome. Apparently the local concentration at these places is due to some peculiar surface condition.

Geologic investigations show that sulphur waters in the Gulf Coast section of Texas and Louisiana occur in one or more of three, or possibly four, conditions. At Barber's Hill, Hockley, and Damon Mound, they no doubt come directly from the buried domes, since at these places the sulphur content in the water is greater over the dome than it is in the territory immediately surrounding it. Hydrogen sulphide gas occurs abundantly in marshes, lagoons, and swamps throughout the entire coast country, where large amounts of decaying organic matter are found. It is common around the heads of bays, where deposits of such organic matter have been covered with recent sediments. Numerous wells and springs in

which the water is derived from sands in contact with such deposits, show this gas. In a few instances, deposits of selenite are apparently the source of both sulphates and sulphides in the water. Finally, it is quite probable that the sulphur water in a number of localities more or less remote from known salt domes has the same source as the deep waters directly associated with a buried salt core.

To summarize, the occurrence of comparatively shallow waters showing varying concentrations of sulphates and hydrogen sulphide throughout the salt dome belt of Texas and Louisiana, is more or less general. Geological examinations of a number of localities where high concentrations were found over small areas show the mineralization to be due in most instances to surface conditions and not to buried domes. Actual drilling has practically condemned several of the most promising areas, emphasizing the fact that new salt domes are not readily located on the evidence of sulphur water alone. That it becomes increasingly difficult to find additional domes is apparent when we consider that of the forty known domes in the Gulf Coast, thirty-seven were found from 1901 to 1913. Of the other three, two were found in 1917 and one in 1922. Since the discovery in 1917 of the Hager-Martin dome in Sec. 28, T. 9 S., R. 7 E., St. Martin Parish, Louisiana, approximately 675 wildcat wells have been drilled in search of new domes on the coast, involving an expense estimated at $20,000,000, exclusive of the cost of leases and overhead expenses. Yet only one new dome has been found during this period and it has not yet proved profitable commercially as a source of oil.

CHEMICAL RELATION OF SALT DOME WATERS

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ABSTRACT

The chlorine content of ground waters from Louisiana and Texas salt domes has been found useful in identifying the source of the waters and in correlation of water-bearing sands. The amount of chlorine is lowest in the near-surface waters and increases downward, reaching saturation near the salt of shallow cores but in domes of the deep-seated type rising gradually at a rather uniform rate below the 2,000-foot level. In several cases structure of the rocks is clearly suggested by chlorine concentration in ground waters.

Thinking possibly that the analyses of oil-field waters might serve to aid us in the development of the coastal fields, numerous water samples were collected at Edgerly, Louisiana.

Samples from various depths, both within the field and from outlying wells, were analyzed. At first a complete analysis was made of each sample procured, hoping a general chemical change would be noted in the waters as their depth increased, or as they became farther removed from the center of the field. The examination of numerous analyses failed to reveal any marked change in oxidation or reduction. The percentage of carbonates in a water in the same sand stratum varied to some extent, due, probably, to local cementation.

A careful study showed that the salt content remained practically constant in waters of each individual water sand over that portion of the area first covered, where correlation of the sands had been definitely established. With this fact known, samples were secured from every test that developed salt water, regardless of location or depth, and a quantitative analysis made for chlorine only. This simplified the chemical work as it permitted analysis in the field. In a short time sufficient data were obtained to prove that chlorine content is constant in the salt water of each individual sand stratum, varying only .1 or .2 per cent over a distance of one and one-fourth miles over the entire field. It was also observed

that the chlorine content increased uniformly between each sand and succeeding deeper water sands.

With this information at hand, it became clear, not only that the salt water could be used as a means of correlation, but that water developed in wells through casing leaks, poor casing seats, faulty seals, etc., could be identified by analysis and the true source of the water determined. In the salt dome fields correlation of the beds is extremely difficult, due to the abrupt thickening and thinning of beds. It is almost impossible to follow any individual sand for any distance, yet the depth of the producing sands remains fairly constant, as though production did not come from an individual sand, but from a zone of numerous sand lenses. Although the sands are not themselves continuous, the salt content of the water remains practically constant for each producing horizon.

The results so far obtained show that the chlorine content of the waters ranges from fresh water near the surface to as high as $6\frac{1}{2}$ per cent of chlorine in sands lying 4,200 feet below the surface, the general average rate of increase being approximately .3 per cent per 100 feet of depth. This rate of increase appears to be uniform only below the 2,000-foot level. This work has been carried on at enough of the Gulf Coast salt domes to show that the relations set forth apply only to domes of the deep-seated type, such as Edgerly, Louisiana, Goose Creek and Orange, Texas, or, in other words, where the producing sands have not been intruded by the cap rock or salt mass. In domes where the salt has penetrated nearly to the surface and has cut through the producing sands, the chlorine content gradually increases to the point of saturation as the water-bearing sand approaches and abuts upon the salt core.

In the Edgerly field four producing sands and samples of salt water taken from these horizons show:

Depth of Sand	Per Cent of Chlorine
2,700 feet	1.9
2,900 feet	2.1
3,000 feet	3.5
3,100 feet	4.1

Samples taken from ten wells producing from the twenty-seven hundred foot sand, and so located that a line joining them extends

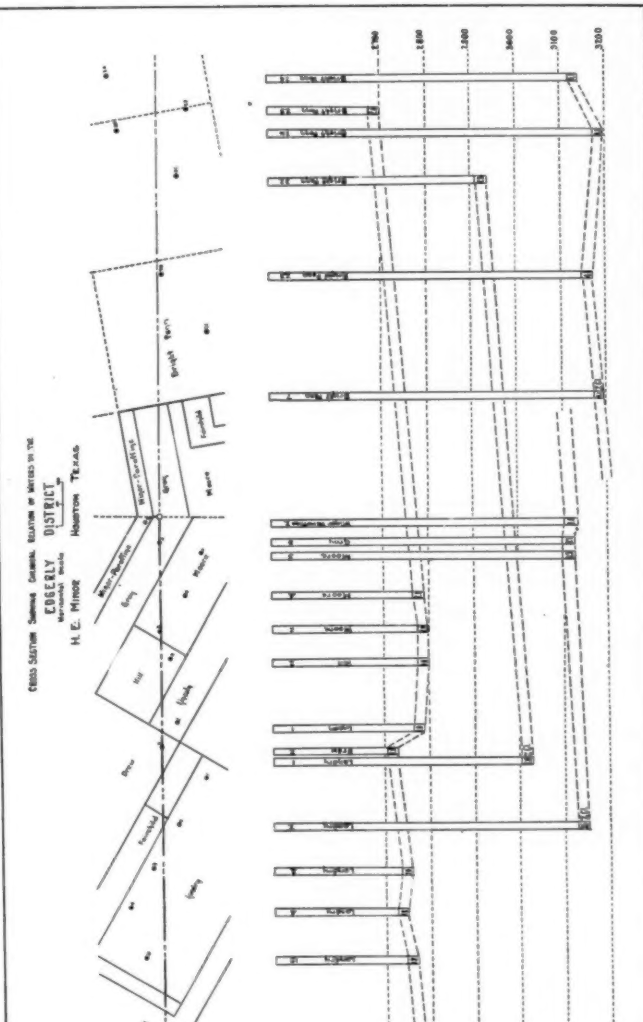
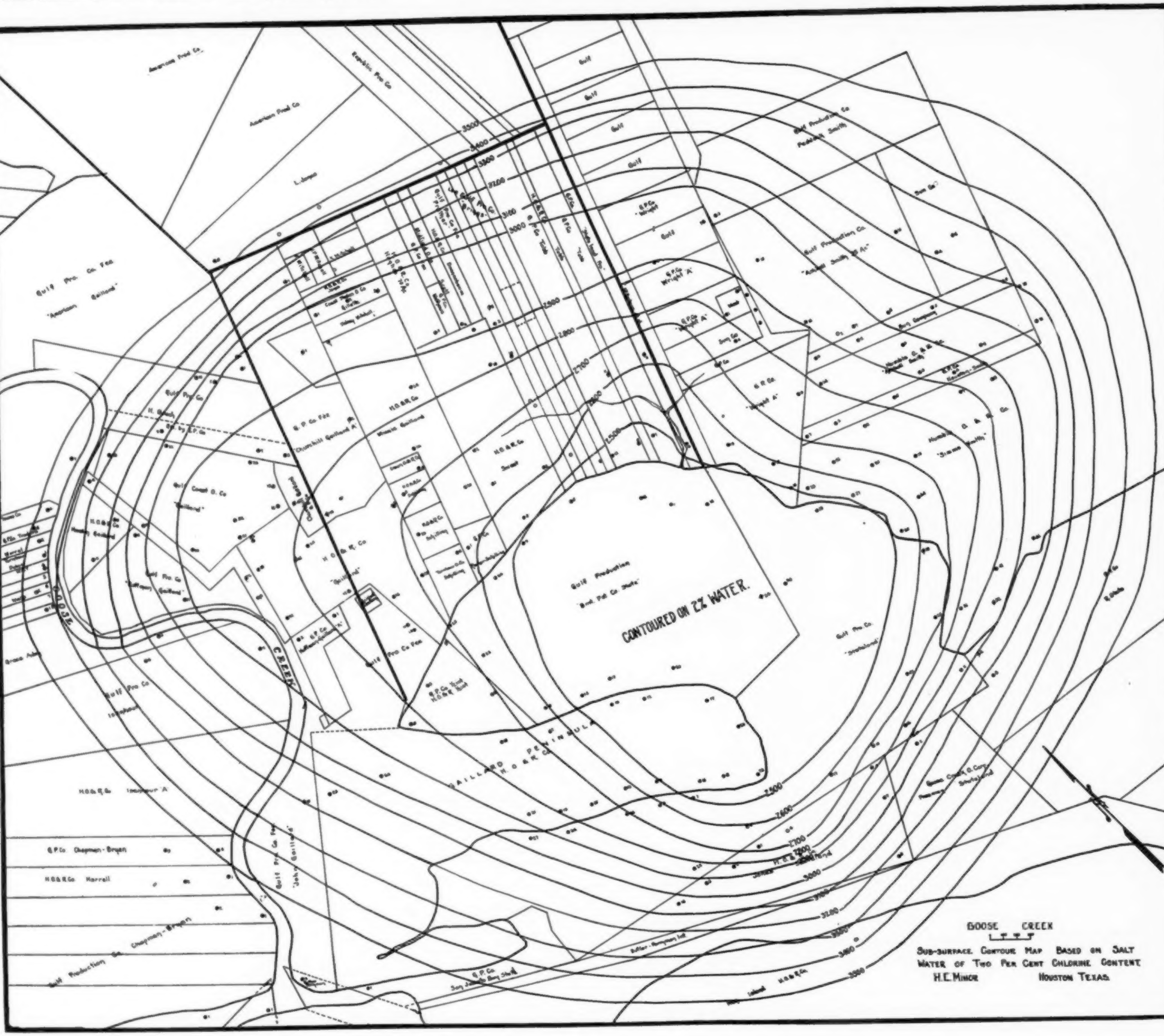
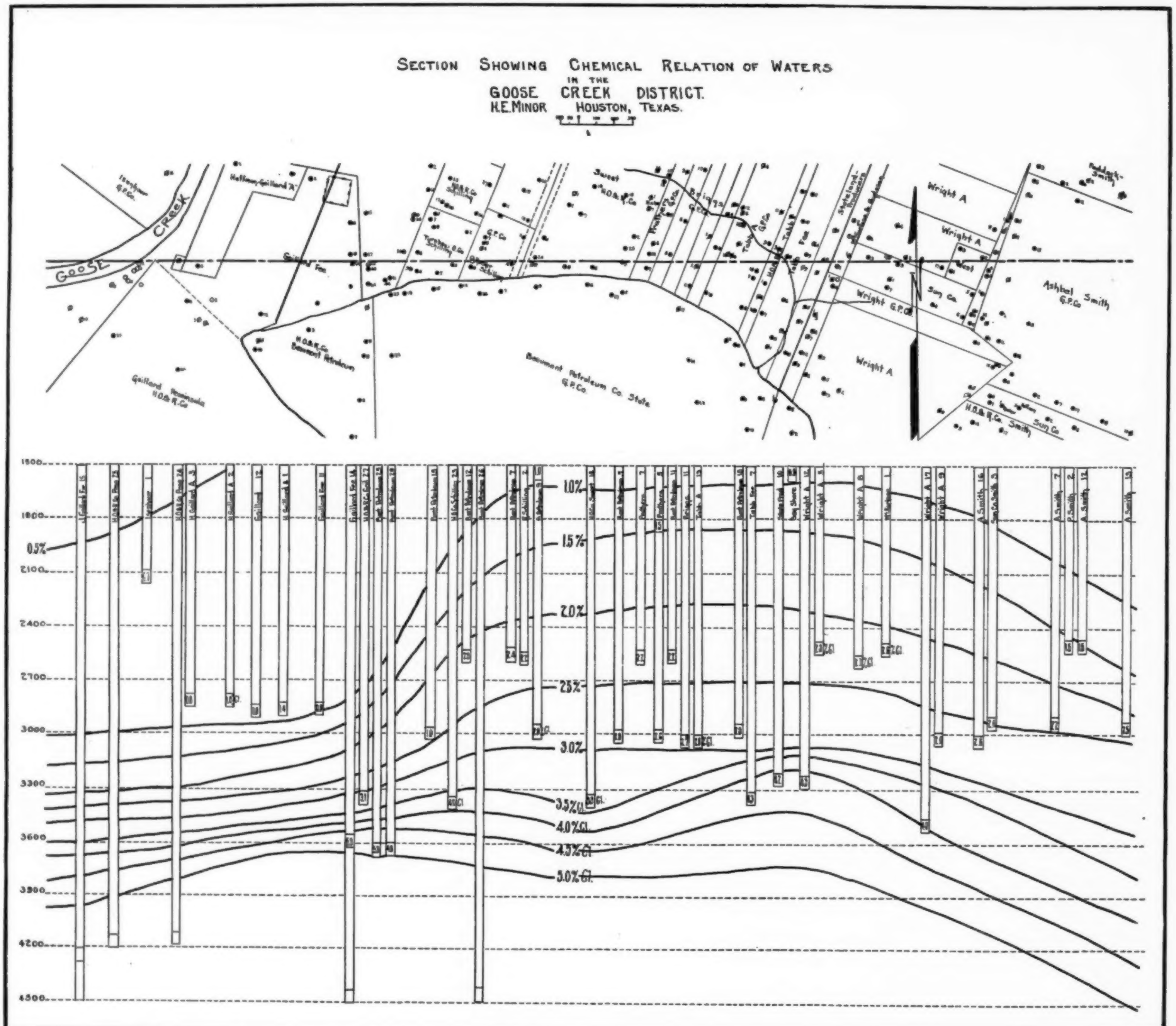


FIG. 1


CONTOURED ON 2% WATER.
GOOSE CREEK
SUB-SURFACE CONTOUR MAP BASED ON SALT WATER OF TWO PER CENT CHLORINE CONTENT
H.E. MINOR
HOUSTON TEXAS
GOOSE
CREEK
GAILLARD PENINSULA
Gulf Production
Gulf Pro. Co. Fee
"American Gaillard"
Gulf Production Co.
"Ashbel Smith 20 Ac"
Humble O. & R. Co.
"Sloane Smith"
G.P.Co. Chapman-Bryan
H.O.&R.Co. Harrell
Gulf Production Co. Chapman-Bryan
Gulf Pro. Co. Fee
"John Gaillard"
American Prod. Co.
Republic Pro. Co.
2500
2600
2700
2800
3000
3100
3200
3300
3400
3500


SECTION SHOWING CHEMICAL RELATION OF WATERS
IN THE
GOOSE CREEK DISTRICT.
H.E.MINOR HOUSTON, TEXAS.
GOOSE CREEK
Gaillard Peninsula H.O.& R.Co.
Beaumont Petroleum Co. State G.P.Co.
Wright A
Wright G.P.Co.
Sun Co.
Ashbel Smith G.P.Co.
Sweet
1500
1800
2100
2400
2700
3000
3300
3600
3900
4200
4500
0.5%
1.0%
1.5%
2.0%
2.5%
3.0%
3.5% Cl.
4.0% Cl.
4.5% Cl.
5.0% Cl.

practically across the field, varied in chlorine content from 1.8 to 1.9 per cent, or a range of only .1 per cent. The accompanying section (Fig. 1) across the Edgerly field shows the uniformity of the chlorine content in the salt water encountered in this sand.

In two of the Gulf Coast fields faults are indicated by the abrupt change in the percentage of chlorine content of waters of equal depth, the downthrown block containing waters less saline than waters found at a corresponding depth on the upthrow side. With sufficient data regarding chlorine content of waters in a field, the amount of displacement of faulted beds might be approximately determined.

In the Goose Creek field conditions are found to be almost identical with those at Edgerly. The analyses of waters from the John Gaillard lease to the Paddock Smith lease, comprising an area 2 miles in length by 700 feet in width, have been plotted. The domed structure of the strata is clearly shown by the chlorine content of the waters (Plate 1).

Upon the map of Goose Creek are shown the lines of equal salt concentration, or what might be called a salt water subsurface contour map. The contours shown are those of a 2 per cent water, and it is interesting to note how closely they conform to the area of actual production. Although some of the largest wells at Goose Creek do not lie within the inner contour, yet the center contour is the approximate center of production (Plate 2).

When these relations are once established in a field, they may be used in many ways. For example: A well at Goose Creek was finished at 3,260 feet, and a screen set from 2,940 feet to 3,060 feet, and from 3,230 feet to 3,260 feet. It produced 4,000 barrels of salt water with a small amount of oil. The water analysis showed 2.2 per cent of chlorine. This chlorine content corresponded to that of 2,900 feet of water. An inside packer was set in the upper screen, cutting off the water and converting the well into a flowing oil well. Geochemical work of this character tends to place geology on a more practical basis and enables the geologist to assist in solving many problems which arise in the development of oil fields.

PETROGRAPHY OF SALT DOME CAP ROCK[1]

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ABSTRACT

Two kinds of cap rock are differentiated: the gypsum anhydrite-cap and the calcite cap. The gypsum is derived from the anhydrite by hydration and is characteristic of the upper part of the cap, where it contains much calcite and sulphur. The deeper, less altered part of the anhydrite cap shows parallel banding, which may be the result of diffusion, and breccia fragments of a parallel-banded, finer-grained anhydrite, which give evidence of sedimentary origin. Therefore, although no detrital minerals have been found in specimens of anhydrite cap, this cap is believed to be of sedimentary origin, brought up by an intrusive salt plug from depth. Possible explanations of the presence or absence of anhydrite caps on salt domes are offered. The calcite cap is the product of replacement and penetration by calcite of the sedimentary beds adjacent to the gypsum-anhydrite cap and probably of the upper part of the gypsum-anhydrite cap itself. The sulphur in cap rock is characteristically associated with this calcite. The calcite and sulphur are probably the result of reduction of the outer parts of the anhydrite cap by hydrocarbons from adjacent beds. Constituents of minor importance are sulphides, carbonates of an early generation, barite, celestite, bipyramidal quartz crystals, and inclusions of sandstone in anhydrite.

THE TWO TYPES OF CAP ROCK

The cap rock of the Gulf Coast salt domes is of two kinds, which may be defined as the calcite cap and the gypsum-anhydrite cap. The calcite cap has generally gone by the name of "limestone" cap, but for reasons that will appear, the writer prefers to call it calcite cap.

THE CHARACTER OF THE GYPSUM-ANHYDRITE CAP

An unusually complete core of gypsum-anhydrite cap was very generously lent to the United States Geological Survey by the Union Sulphur Company. This is a practically complete 2-inch diamond-drill core taken between the depths of 670 and 1,468 feet, an interval of about 800 feet, in the company's well No. 194, near the center of the cap-rock area at Sulphur Mine, Louisiana. The core is said to have begun just below the productive rock—that is, probably about at the base of the calcite cap, into which it grades in its upper part—and to have ended on the salt. On account of its gradation to the

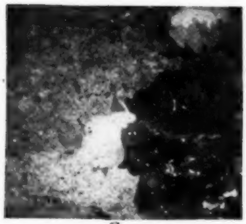
[1] Published by permission of the Director of the U.S. Geological Survey.

calcite cap, it will be taken as a basis for the study of both types of cap rock. The general character of this series is brought out by the first piece of core in it (Fig. 1), which contains all the dominant constituents of the series—gypsum, anhydrite, calcite, and sulphur—in their characteristic relations. A detailed consideration of this piece will therefore prepare the way for a more rapid review of the rest of the series.

The hand specimen appears to be almost pure, dark grayish-black translucent gypsum with traces of banding at a low angle and with slight veinlets of calcite running into druses, in one of which a crystal of sulphur can be seen.

The thin section (Fig. 2) shows large gypsum crystals made up of small elements that have nearly the same orientation. At one end are many disseminated calcite crystals, undoubtedly adjacent to one of the calcite veins (Fig. 4); at the other end, much residual anhydrite (Fig. 6), some of the crystals of which have common orientation with one or more adjacent crystals. This common orientation (which does not appear in the area included in Figure 6) and the corroded outline of the anhydrite crystals, as compared with the rectangular form which characterizes them in typical anhydrite cap rock, constitute the only evidence in support of the assumption that the gypsum of this specimen is derived from the hydration of a rock made up originally of anhydrite. This derivation will be more conclusively demonstrated by subsequent illustrations from deeper parts of this same core (cf. Figs. 9 and 10).

In Figure 6, the line of dark impurities lettered *b* marks the boundary between the two elongated gypsum crystals numbered 2 and 3 in Figure 2. On each side of this line, the entire area represented is essentially a single gypsum crystal. This brings out the fact that here, as usual, a single large gypsum crystal replaces several smaller crystals of anhydrite, apparently owing to a molecular mobility of gypsum which results, it may be supposed, from its solubility. This causes a tendency toward arrangement in common crystallographic orientation with crystals adjacent to it. The common orientation of crystals, parallel to the banding, is undoubtedly due in part to pressure. Even the three major gypsum crystals that make up the section shown in Figure 2 have extinction positions



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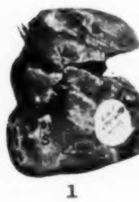

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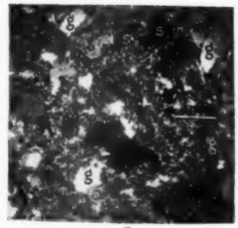

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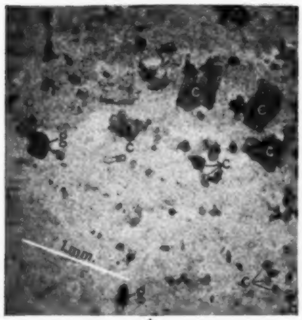

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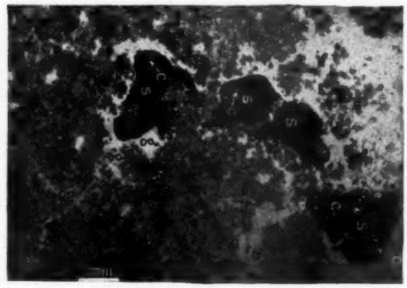

5

6

FIG. 1.—Dark gray translucent gypsum, with open fissure partly lined with calcite and merging into calcite veins.

At *v* calcite veins in solid rock. At *b* banding at low angle of dip, due to planes of weakness. At *s* a single sulphur crystal in an open fissure. Corë from 670 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana. First piece of core in the series.

FIG. 2.—Thin section from specimen of gypsum shown in Figure 1, crossed nicols

1, 2, and 3 are the three principal crystals that make up the section. Note how near 2 and 3 are to simultaneous extinction. In 1 note the slightly patchy extinction in many small areas with more or less rectilinear boundaries and differing only very slightly in extinction position. This does not refer to the bright white elements scattered about especially in the lower right-hand corner, most of which are fragments broken loose in grinding the section.

FIG. 3.—Remnants of gypsum (*g*) in a matrix of fine-grained calcite

s marks two adjacent remnants of gypsum with simultaneous extinction indicating that they were at one time continuous. Thin section of a specimen from a depth of about 1 foot below that of Figures 1, 2, 4 and 6. Crossed nicols.

FIG. 4.—Calcite crystals (*C*) in gypsum

Detail of the thin section shown in Figure 2, crossed nicols. From the concentration of the calcite in this neighborhood, it is very probable that a calcite vein occurred just outside the area covered by the thin section.

g marks gypsum crystals oriented differently from the surrounding area. No attempt has been made, of course, to indicate all the calcite crystals that can be seen in the illustration.

FIG. 5.—Sulphur (*s*) penetrating fine granular calcite

Thin section from a specimen just below that of Figure 3. Note at *c* the calcite crystals, like those of the matrix, surrounded by sulphur. *g* marks gypsum crystals. Almost all the other clear spaces are holes in the thin section.

FIG. 6.—Remnants of anhydrite (*a*) in the midst of gypsum

Detail of another part of the thin section shown in Figure 2. The gypsum crystals in which the anhydrite occurs are those marked 2 and 3 in Figure 2, and *b* marks the boundary between them. *h* marks holes in the thin section, *h a* apparently one from which anhydrite has been torn. *c* marks calcite crystals.

very near one another, indicating that they are approaching a common orientation. It is important to keep this tendency in mind, for in effect it seems to imply great plasticity in the gypsum; that is to say, if by pressure and movements the gypsum were broken into many small fragments, it would tend to reconstitute itself into large, fresh-looking elements showing no trace of the disturbances it had undergone.

To summarize the phenomena illustrated by this specimen, there is evidence of an original anhydrite rock in which gypsum has largely replaced the anhydrite, single large gypsum crystals taking the place of a large group of anhydrite crystals. Remnants of anhydrite crystals in the gypsum indicate its origin. Fissures and cavities in this gypsum have been veined by calcite, and adjacent to these veins the gypsum has been penetrated and replaced by calcite. A cavity in the gypsum contains a crystal of sulphur. The relation of the sulphur to the calcite is not made clear by this specimen, but evidence to be brought out below will show that sulphur is generally later than the calcite or partly contemporaneous with it.

The paragenetic sequence here, then, is anhydrite, gypsum, calcite, sulphur, and this is the sequence in all specimens the writer has examined.

Below the piece of core just described, there is about a foot of gypsum like this specimen, then 2 or 3 inches of a rock in which calcite predominates. That this rock also is derived from a gypsum rock is indicated by the presence, in parts of it, of abundant fragments of gypsum (Fig. 3), which, by their corroded boundaries, by the way they are penetrated by the granular calcite, and above all by the simultaneous extinction of adjacent fragments, indicate that, like the anhydrite in the gypsum of Figure 6, they are remnants of a rock that consisted at one time dominantly of gypsum. Sulphur, in irregular bodies, is common all through this rock. Figure 5, which represents a thin section from the core fragment just below that represented in Figure 3, shows that the sulphur, like the gypsum, is irregularly interpenetrated with the calcite. But there is this difference, that the sulphur includes entirely within its area little calcite masses, so that here it is apparently the sulphur that is later and has come in to replace the calcite.

Although there are no sharp limits to the vertical distribution of different types of rock in this series of core fragments, there is nevertheless a fairly regular development in the character of the predominant type of rock from the top to the bottom, and the differences involved may be most readily grasped if the facts are generalized and the core is described and subdivided somewhat arbitrarily. The subdivisions are represented diagrammatically in Figure 33, p. 75.

The first subdivision may be taken to extend through about 130 feet, from the top of the core at 670 feet to about 803 feet. This part is characterized by the features described above: abundance of calcite as a secondary mineral invading gypsum, which in turn shows scattered crystals of anhydrite, remnants of the anhydrite rock which it has replaced, and the calcite and earlier rock constituents in their turn invaded by sulphur as the latest mineral. Sulphur occurs not only as irregular small bodies within the calcite rock, but also in well-defined calcite veins in the gypsum rock, either filling the central part of the vein or as well-developed terminated crystals lining druses in the veins. The specimen shown in Figure 7 may serve as a type of this part of the section.

The second subdivision of the cap may be made to include the interval of about 150 feet, from 803 to 948 feet. The country rock of this part, instead of being gypsum with scattered crystals of anhydrite, either is anhydrite rock, veined with gypsum that may contain scattered anhydrite crystals, or plainly shows its origin as anhydrite rock by the presence of anhydrite as a dominant constituent in a matrix of gypsum that has clearly replaced anhydrite. Calcite no longer appears as veins or disseminated in gypsum adjacent to veins, but merely as large single crystals scattered through the anhydrite; sulphur veins and the cavities in the rock have also disappeared. In this subdivision and the one below it, the sulphur occurs mainly disseminated through gypsum and anhydrite or as thin films along planes of weakness.

The second division of the section may be illustrated by Figure 9, which shows a specimen from the upper part, at 830 feet. In this specimen the hydration, or more definitely the gypsification, clearly invaded the anhydrite rock along bands presumably of greater permeability. Close examination of the figure shows that there are

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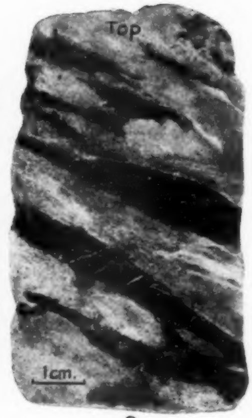

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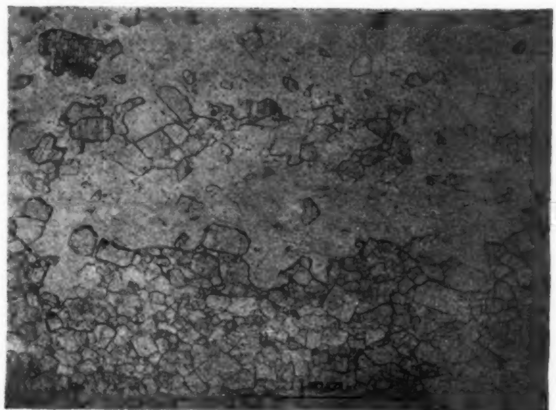

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FIG. 7.—Dark-gray gypsum veined and penetrated by light-colored calcite and by sulphur.

The replacement and penetration of the gypsum, adjacent to the veins, by calcite, is especially well shown. *g* marks gypsum, *c* calcite, *s* sulphur. Exterior of a core from 796 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

FIG. 8.—Gypsum bands at high and low angles of dip in anhydrite

The darker portions are gypsum of various degrees of purity. Polished face of a core from about 836 ft. in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

FIG. 9.—Anhydrite interbanded at low angles of dip with gypsum

The dark bands are translucent gypsum; the light bands finely granular anhydrite. Polished face of a core from about 830 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

FIG. 10.—Contact of a band of gypsum and a band of anhydrite

Thin section from specimen shown in Figure 9. The gray, almost structureless area in the upper part is gypsum, the well-defined crystals are anhydrite.

differences in texture within the anhydrite itself. These are due to differences in size of grain, the denser, whiter portions being the finer-grained. These finer-grained portions of the anhydrite are probably the less altered. The alteration, as in the gypsum, is apparently a result of the solubility of the anhydrite and seems to indicate that water penetrated into the anhydrous rock and, without combining with the anhydrite, partly dissolved and redistributed its molecules. As in the case of gypsum, this tendency of the anhydrite crystals to grow has a definite bearing on the plasticity of the anhydrite, in that it suggests that an anhydrite mass might yield and change its shape by crushing and granulation and yet, on account of this molecular mobility resulting from its solubility, be reconstituted as well-crystallized anhydrite. Under the microscope (Fig. 10) the general structure along the contact of a gypsum and an anhydrite band in the specimen of Figure 9 appears very clearly—a band of solid anhydrite on one side and a band of gypsum with scattered and somewhat corroded anhydrite on the other. Notice, as compared with the gypsum of Figures 2 and 4, the independent development of most of the anhydrite, in the solid anhydrite portion, as chunky, rectangular crystals, each oriented altogether independently of the others except for a slight prevalence of elongation parallel to the banding of the rock.

The gypsum elements in the gypsum band shown in Figure 10 do not have the high degree of common orientation of the gypsum of Figure 6, though most of them extinguish near a position that makes a slight angle with the banding.

In Figure 9, the gypsum bands dip at low angles. Figure 8 shows a specimen from about 6 feet below that of Figure 9, in which the banding by gypsum is at high as well as at low angles. These two distinct directions of gypsum banding occur throughout the anhydrite of this cap, but the low-angle banding is the more common.

In the third subdivision of the section, extending from a depth of 948 feet to the bottom of the cap at 1,468 feet, solid anhydrite is dominant; gypsification is of minor extent, and veining by calcite and sulphur are negligible, although pieces of core obtained within 43 feet of the bottom consist dominantly of gypsum with thin veins of calcite like those near the top, and sulphur in intimate association

with this calcite. About 50 feet at the top of this subdivision may be separated as a transition zone, leaving the interval of about 460 feet from 1,004 to 1,468 feet as that in which solid anhydrite predominates.

Three features are characteristic of the anhydrite rock of this third or basal subdivision: (*a*) banding in the mass of the anhydrite rock, dipping at low angles and not due to gypsification, (*b*) evidence of violent brecciation and flowage, (*c*) breccia fragments of a distinctive dense white fine-grained anhydrite that is also banded.

The first type of banding referred to above occurs at irregular intervals. It is present in some pieces of the core and absent in others. The banding takes the form of dark, nearly parallel lines, like bedding lines, running through the granular, sugary type of anhydrite that predominates in the gypsum-anhydrite cap. Some of the bands exhibit a difference in texture accompanied by a difference in color of the anhydrite on opposite sides of the dark lines, dark anhydrite occurring on one side and light on the other. Elsewhere there is a gradation from dark to light anhydrite between two consecutive lines, and in still others a more or less sharp boundary between the dark and light anhydrite occurs without any line between them. Where dark and light anhydrite occur on opposite sides of a dark line, they invariably bear the same relation to the line, the dark anhydrite occurring above it, the light below it.

Figure 8 shows the highest specimen, among those selected for polishing, in which indications of this banding could be recognized, but only by tracing the banding upward from specimens in which it is more definitely developed was it identified in this one. Distinct banding does not appear much above a depth of about 1,200 feet, but is common from this depth to the bottom of the core. The best development of this banding is illustrated by Figure 13. The irregularity of the banding in the specimen shown in Figure 8 is assumed to be due to gypsification, the dark lines being gypsum. The flatness and parallelism of the banding is not perfect in all ungypsified specimens, but is as nearly perfect as much sedimentary bedding.

Brecciation and flowage, the second feature characteristic of the third or basal subdivision of the section, were first noticed in the first specimen in which heavy gypsification ceases and anhydrite be-

comes a dominant constituent, at about 982 feet. Examples of brecciation and flowage occur from this level down to the bottom of the core, though among the specimens selected for polishing, brecciation and flowage are most common between about 1,250 and 1,300 feet.

The third characteristic feature of this subdivision of the section is the character of the breccia fragments, which consist of a distinctive white anhydrite that is denser, whiter, and finer grained than the anhydrite in which they are imbedded or than unbrecciated anhydrite in general, and that is marked with parallel black lines. These lines, which, like those in the unbrecciated anhydrite, may be due to impurities, appear broader than those in the coarser unbrecciated anhydrite, and the contrast with the dense white anhydrite, which has the same texture and color on both sides of them, makes them stand out more sharply. Figures 12 and 15 illustrate anhydrite of this type in different stages of brecciation and flow. There are some indications that disturbance increased with depth. Figure 14 shows the dense white, strongly banded anhydrite, slightly faulted and with more flow structure than brecciation, in association with the other type of coarser-grained, parallel-banded anhydrite that appears at the bottom of the core. Figure 11 illustrates a more complicated and intimate association of these two types and more extreme brecciation of the dense white rock. As the dense white anhydrite with pronounced parallel banding occurs invariably as breccia fragments in the more coarse granular, darker, more sugary rock, it must be an earlier phase of the anhydrite.

What is admittedly an extremely generalized description of the material from this well of the Union Sulphur Company may be summarized briefly as follows (see Fig. 33, p. 75): There is at the bottom dominantly a pure anhydrite rock in which two forms of structure have been differentiated—a breccia of dense, white, banded anhydrite in a matrix of coarser anhydrite, and parallel low-angle banding in the coarser rock itself. The dense white rock with parallel low-angle banding was nowhere encountered undisturbed. There has been in the coarser-grained anhydrite some gypsification at intervals, some calcification following presumably more permeable layers (as at *c* in Figure 13), and very slight calcite veining, with sulphur in-

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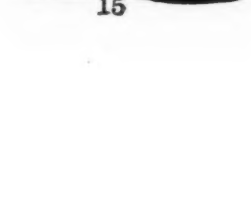

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FIG. 11.—Parallel-banded coarse-grained dark anhydrite interbedded with distorted, dense white, parallel-banded anhydrite.

a marks fragments of dense white anhydrite cut off sharply by overlying bands of coarser anhydrite. Polished face of a core from about 1234 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

FIG. 12.—Brecciated fragments of banded dense white anhydrite in a matrix of coarser gray anhydrite.

Polished face of a core from about 1197 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

FIG. 13.—Anhydrite showing well-developed roughly parallel banding at a low angle of dip.

The white patch at *c* is rich in calcite. Polished face of a core from about 1,440 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana. As the core lay in the box, the end with this calcite-rich patch is the bottom, but from the relations of the dark and light portions (as explained in the text) in the bands of the rest of the specimen, it is probably the top.

FIG. 14.—Dense white anhydrite with pronounced parallel banding, only slightly distorted.

Coarse-grained anhydrite with parallel horizontal banding just shows at the bottom. The black spots in this coarse-grained anhydrite are gypsum. *ff* marks faults with slight displacement. Polished face of a core from about 1251 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

FIG. 15.—Dense white banded anhydrite strongly brecciated and distorted

Polished face of a core from about 1294 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

troduced either adjacent to the calcite veins or in association with calcite along planes of weakness in the rock.

Farther up, gypsification is more common, the gypsum occurring both in bands that dip at low angles, which may be determined by the low-angle banding preserved in the deeper-lying rock (although the gypsum bands lack the pronounced parallelism of that banding), and, less commonly, in bands that dip at high angles, following planes of weakness that must have resulted from bending and cracking either because of upward movement of the salt core or because of pressure produced by the gypsification itself. As the gypsification increases upward, the dark gypsum with remnants of light-gray anhydrite rock floating in it becomes the dominant constituent, until finally the anhydrite can be found only under the microscope as remnants of isolated crystals scattered through the gypsum. With the increase of gypsification, replacement and veining by calcite and sulphur also increase.

In the general form here given, this description probably applies to the rock in its original condition. In some of the calcitic, sulphur-bearing specimens from the upper part of the core, there were conditions suggesting alterations by the water used in the extraction of sulphur, but as the core begins at the bottom of the productive cap, it is probably little altered. Nevertheless, it is very desirable to obtain a core through the entire cap, from some dome on which there has been no extraction of sulphur, or, for that matter, even of oil.

The writer has not studied any other gypsum-anhydrite cap consistently and can therefore not be sure that the general features observed here are those of most other gypsum-anhydrite caps; but from what he has seen, it appears that extensive gypsification in the upper part is general. Some indications of the sharp, parallel, low-angle banding were noted in cores from other domes, and breccia fragments of the dense white anhydrite showing parallel banding—in some fragments much distorted—were seen in material from two other domes. Moreover, it is probably safe to say that where there is a cap over a salt plug, the foundation of the cap is generally anhydrite.

THE ORIGIN OF THE ANHYDRITE CAP

The interpretation of the characteristics described involves the consideration of the origin of the anhydrite cap. The gypsum will henceforth be left out of consideration, as its derivation by hydration of the anhydrite cap seems, in most cases at least, so obvious as to leave no room for doubt.

ALTERNATIVE HYPOTHESES

During this investigation the writer has had in mind four generally recognized hypotheses for the origin of the anhydrite cap: (1) It crystallized from solution, at the top of the salt plug, from underground waters. (2) It segregated as the insoluble residue from the solution, by meteoric waters, of the top of the salt plug as the plug moved up. (3) It was formed by the action of sulphuric-acid water on limestones encountered by the salt plug in its upward passage. (4) It is part of an original sedimentary bed of anhydrite which overlay a bed of sedimentary salt in depth, and as this bed of salt was folded and finally squeezed upward at the apex of the fold in the form of a salt plug, it pushed a layer of the overlying anhydrite ahead of it.

This last hypothesis is the one that is advocated in the following discussion. It is not desired to argue that all the evidence to be presented supports only that interpretation; much of it might be interpreted in favor of another origin. But the evidence has been organized around the hypothesis of sedimentary origin because, taken as a whole, it seemed most to support that hypothesis.

GENERAL CONSIDERATIONS

The most direct reason for assuming a sedimentary origin of the anhydrite cap is that such an assumption is a simple extension of the interpretation of the origin of the salt plug itself from a sedimentary bed—the interpretation that is most commonly accepted on general geologic grounds. A hasty review of stratigraphic sections containing salt beds shows that in a great many sections a bed of anhydrite is found above the salt bed.

In looking for evidence on the origin of the anhydrite cap, it must be recognized that the cap has evidently undergone extensive alteration and that this alteration may have proceeded so far and through so many different stages as to obliterate all evidence regarding the

origin of the cap. The object of the petrographic investigations, therefore, was to determine the character of the earlier stages of the rock. The dense white breccia fragments, as pointed out above, must evidently represent an early stage. As the abundance of these fragments in the deeper part of the core and of the secondary products—gypsum, calcite, and sulphur—in the higher parts suggests that the deeper parts are less altered, it seems that the straight, parallel, low-angle banding of the coarser-grained anhydrite, which is also more common in the deeper parts, may likewise represent an early stage in the formation of the anhydrite cap. The banding of both types of rock will therefore be considered in its bearing on the origin of the anhydrite cap.

ORIGIN OF THE BANDING

Evidence from the larger features as observable in hand specimens.—The mere presence of parallel banding in both these types of material suggests sedimentary origin, but other possible explanations of this banding must be considered.

Shearing and flowage under pressure suggest themselves, but the parallelism and continuity of the dividing surfaces are opposed to this assumption, because a number of specimens of undoubtedly sheared and squeezed anhydrite cap rock, as illustrated in Figures 16, 17, and 18, show contorted and irregularly diverging surfaces and lenticular structure like gneiss and schist. The large, dark inclusion shown in Figure 17 is a fragment of sandstone, and the dark bands in Figure 16, which is a front view of the same specimen, are layers of this same sandstone dragged out with remnants of the bedded sandstone surviving, as shown by the thin section illustrated in Figure 19.

A third possible mode of origin of the banding, suggested by Professor A. C. Lawson in the discussion of this paper when it was presented at the Houston meeting of the Association on March 26, 1924, is that these parallel surfaces might be produced by diffusion accompanied by rhythmic reaction of the Liesegang type, such as can take place in colloids or in any homogeneous medium that permits slow and regular diffusion. The homogeneity of the layers in the dense white breccia fragments, as they appear in the hand specimens, and their resemblance to sedimentary layers afford no evidence that

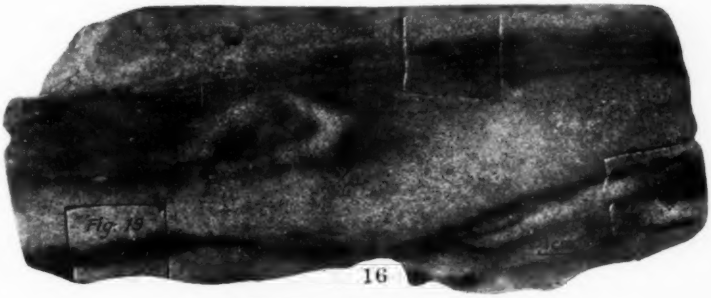

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FIG. 16.—Coarse-grained anhydrite showing flowage

Polished face of a core from 500 feet in the Gulf Production Company's well No. 5, at Hockley, Texas.

FIG. 17.—Reverse side of right-hand end of specimen of Figure 16, showing sandstone inclusion along the black sandy seam in the bottom of Figure 16.

FIG. 18.—Schistose anhydrite

Polished face of a core from 3,055 feet in the Humble Oil and Refining Company's Lizzie Singer No. 2 well on the Palangana salt dome, near Benavides, Duval County, Texas.

might be used in support of this hypothesis, but the parallel bands in the coarser mass of the anhydrite have three characteristic features that may favor it.

One of these features is the close interspersing of these bands with brecciated portions, as illustrated in Figure 11. It may be assumed either that the brecciation took place at the time of deposition, before the overlying undisturbed layer was deposited, or that it took place after deposition, presumably after consolidation and during the tectonic disturbance that produced the salt dome, without disturbing the original sedimentary banding of intermediate layers. The objection to the first assumption is that, as can be seen at the bottom of the specimen illustrated in Figure 11, the parallel banding in the dense white breccia fragments themselves is curved and contorted in a way that it seems likely could result only from great pressure and after consolidation of the fine-grained white anhydrite fragments. The objection to the second assumption is that selective brecciation of such narrow layers seems unlikely in a sequence of material that was probably fairly uniform. These difficulties are met by assuming that this banding is due to diffusion; but, on the other hand, it seems doubtful whether the brecciated material, as illustrated, for instance, in Figure 11, would be uniform enough to yield such straight and parallel bands by diffusion through it. The evidence from this feature in favor of origin by diffusion is therefore doubtful.

The second feature supporting the idea that this banding originated by diffusion is the relation of the banding lines to the fine-grained breccia fragments. In looking over and discussing this series of cores in the laboratory of the United States Geological Survey some time after the Houston meeting, Dr. Donald C. Barton pointed out that the parallel low-angle bands in the coarser-grained anhydrite apparently without exception cut off abruptly the *tops* of the brecciated layers, cutting right through individual breccia fragments of the dense white anhydrite, as can be seen at the points marked *a* on Figure 11. This observation seems to favor the idea that these bands may have been produced by diffusion, though the condition might also be due to solution by the water in which the anhydrite was deposited, before deposition of the overlying bed and after brecciation.

The third feature supporting the hypothesis of origin by diffusion is the change noted above, and shown by Figures 11 and 13, from light-colored material in the top to dark in the bottom of some of the layers. But this feature also might be of sedimentary origin.

Microscopic evidence.—The most conclusive microscopic evidence regarding the origin of the banding is in the fine-grained breccia fragments. The best example is furnished by the core illustrated in Figure 20. This core was in the collection of the late G. Sherburne Rogers, of the United States Geological Survey, who, to the great loss of geology, was drowned while engaged in field work in South America shortly after he began the study of salt domes for the Survey. As no label or record of any kind could be found with this specimen, the writer would be greatly obliged, in case anyone recognizes it, for information as to its origin.[1] The large number of coarse breccia fragments in it and the large proportion of them that show good banding make it unique so far as the writer's experience goes.

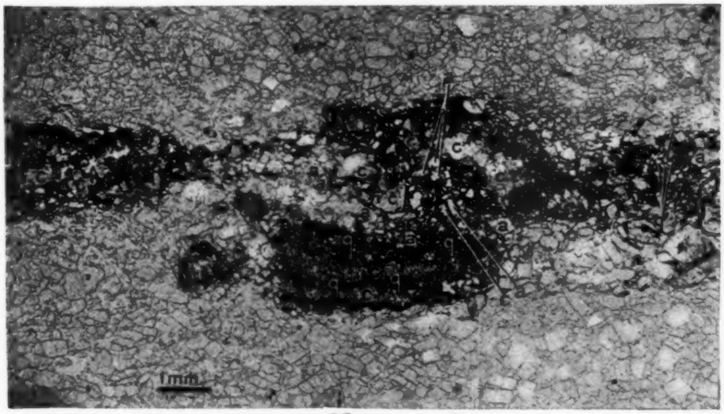
In this core the difference between breccia fragments and matrix is sharper than in the Sulphur Mine core, and the parallel banding, with dark seams, is very definite in some fragments, though confused by fracturing and by gypsification along the dark seams in many others. Figure 21 shows a thin section of the best-banded fragment. The evidence from this thin section appears definitely to favor the view that the banding is the result not of shearing by pressure or of diffusion, but of periodicity in precipitation, such as would be expected in a sedimentary bed.

The most obvious bit of evidence is the character of the dark bands themselves. Their dark color is due not to any mere difference in texture or to inclusions like sulphides that might be of secondary origin, but apparently to impurities like clay or other fine detrital matter.

Another fact supporting the idea of sedimentary origin is the slight indication, not recognizable in the figure, of a variation in the coarseness of anhydrite layers from one dark band to the next.

Another is the distribution of the carbonates, which show as dark grains in the figure. These appear to be somewhat more numerous

[1] It is possible, though not probable, that this core is not from an American salt dome or indeed from any salt dome.



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20 A

20 B

FIG. 19.—Thin section of a flowage band of sand in the specimen of Figure 16. The location of the thin section is indicated on Figure 16.

The largest part of the band is calcite (*C*) in large pure elements, and in smaller elements more intimately intergrown with the dark impurity which appears to be mainly sulphide (pyrite?). There are also a number of fragments of anhydrite (*a*), some of them in contrast with the country rock, partly gypsified. The quartz-sand grains are so small and scattered that it was not found practicable to indicate them individually except at *q*'. *qq* indicates sandy bands.

FIG. 20.—Coarse, distinct breccia of very sharply parallel-banded dense white anhydrite in coarser anhydrite.

External face (*A*) and polished face (*B*). Origin of specimen unknown.

on the side of the dark bands opposite the coarser anhydrite than on the other side. If these carbonates had been introduced after the formation of the bands by waters circulating along the bands, they should be equally abundant on both sides.

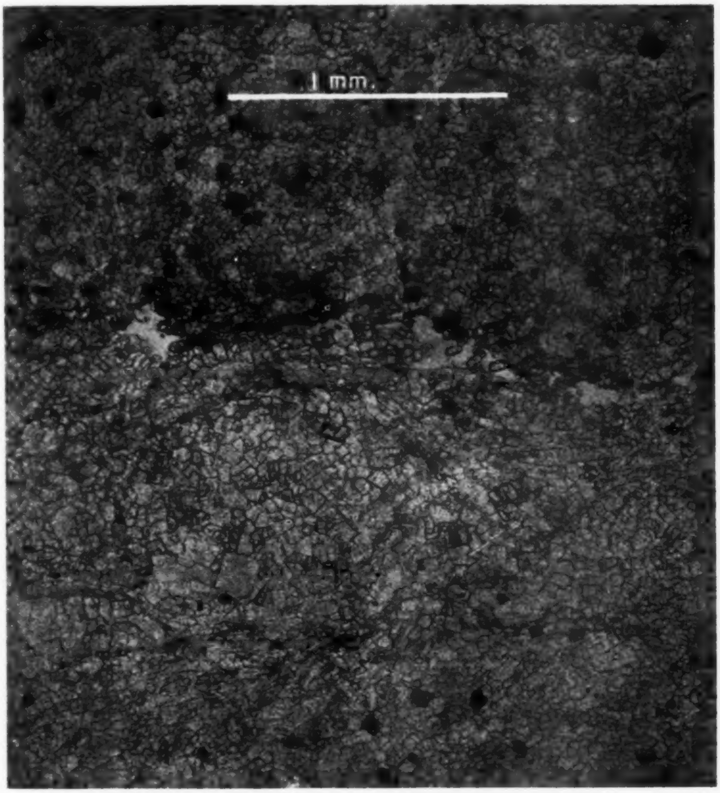


FIG. 21.—Thin section of banded dense white breccia fragment from specimen of Figure 20.

The approximate position of the thin section is indicated in Figure 20

Furthermore, although there are carbonates in both the breccia fragments and the matrix, those in the fragments are mostly dolomite, and those in the matrix are mostly calcite. The dolomite is cloudy and impure looking; the calcite is relatively clear. The dolo-

mite is in distinctly smaller and more regular crystals than much at least of the calcite. Altogether this evidence indicates that the dolomite originated at a different time from the calcite and belongs to a period in the history of the breccia fragments that preceded the brecciation. The presence and the unsymmetrical distribution of these dolomite crystals are just what would be expected in a sedimentary anhydrite rock, for ordinarily the precipitation of the carbonates (dolomite or calcite) precedes the precipitation of gypsum or anhydrite in the undrained bodies of water in which all these substances are deposited, and the more intensive precipitation of the carbonates would have a periodic recurrence with the rainy periods. It is also very probable that the size of the anhydrite crystals precipitated would vary with the concentration of the solution, and in most known examples the crystals grow coarser as the solution grows more concentrated—that is, toward the upper part of a layer. This is the direction of increasing coarseness in the thin section of Figure 21, if the bottoms of the layers are taken to be the parts in which there is the greatest concentration of dolomite.

Support for the hypothesis of sedimentary origin of the banded dense white anhydrite can also be found in the distribution of calcite and anhydrite in a core of banded anhydrite rock of unquestionable sedimentary origin which was kindly supplied by Dr. J. A. Udden. This core (Fig. 24), which came from the Flood well No. 1 in Culberson County, Texas, forms part of a mass of anhydrite over 1,000 feet thick which has been described by Udden.[1] Most of the mass is banded like this specimen. Udden shows that the banding is due to alternate layers of carbonate and anhydrite more or less sharply separated from one another (see Fig. 22), although in some layers the carbonate is less continuous and less definitely limited to a single layer. The carbonate in the thin section illustrated in Figure 22 does not occur in well-defined isolated crystals, as in the breccia fragment of banded anhydrite shown in Figures 20 and 21, but in irregular fragments that lie partly in contact with one another and are elongated parallel to the bedding. Udden illustrates some specimens, however, in which the carbonate is in definite isolated rhom-

[1] Johan August Udden, "Laminated Anhydrite in Texas," *Bull. Geol. Soc. Amer.*, Vol. 35 (1910), pp. 347–54.

bohedra.[1] There is therefore considerable resemblance between the banded breccia fragments of the specimen represented in Figure 20

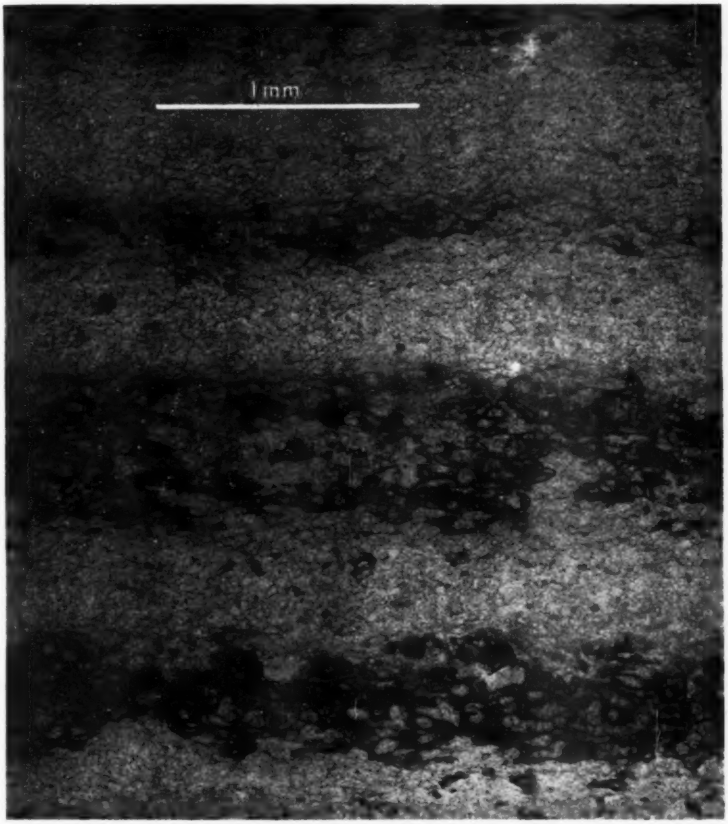


FIG. 22.—Thin section from specimen shown in Figure 24

The dark bands are mostly calcite with much organic matter. The light bands are mostly anhydrite

and this anhydrite of unquestionable sedimentary origin. Although the specimen illustrated in Figures 20 and 21 is conspicuous for the definiteness of its characteristic features, it is probable that the

[1] See especially Fig. 2 of Pl. 10, p. 351, and Fig. 1 of Pl. 9, p. 350, of his paper.

banded dense white fragments in other specimens of the anhydrite cap rock are of the same character.

The remarkable agreement of the microscopic features of the breccia fragments of the specimen illustrated in Figures 20 and 21 with what is found and what would be expected in anhydrite of sedimentary origin points definitely to the sedimentary origin of the

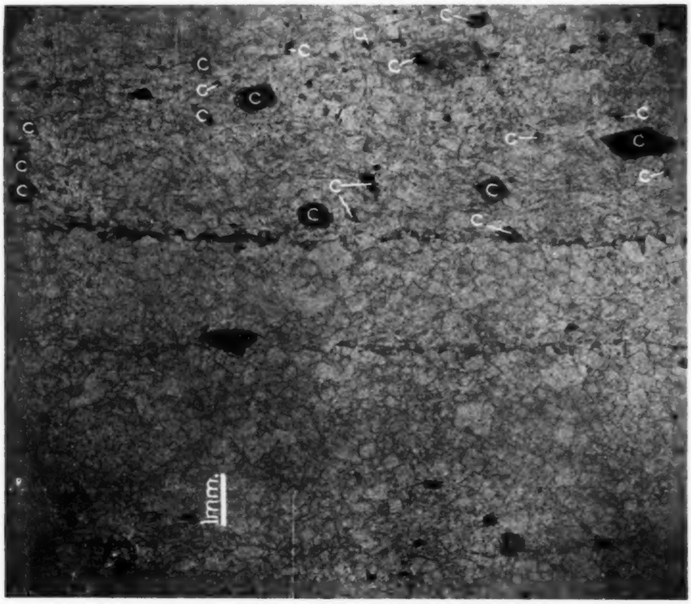


FIG. 23.—Thin section of coarse, undisturbed, parallel-banded anhydrite rock of specimen of figure 13.

c marks crystals of carbonate which, as far as they could be determined, are calcite.

original anhydrite cap. These features might perhaps result from diffusion, but in the absence of any definite knowledge as to how they might be produced by that process, it is hard to believe that there could be so close a resemblance between characteristics produced by sedimentation and those resulting from diffusion.

The microscopic evidence for the origin of the low-angle parallel banding in parts of the core that show no brecciation is not so con-

clusive. Figure 23 illustrates a thin section of material from the specimen of Figure 13. In this section the boundaries of the bands appear very nearly parallel and clearly marked by impurities, but no regular variation in the coarseness of anhydrite crystals across individual bands can be recognized. Carbonate crystals are abundant in some layers, but their very random distribution in the thin section as a whole, the apparently secondary penetration of the rock by calcite as indicated by the white calcareous patch marked *c* in Figure 13, and the general resemblance of these calcite crystals to those found scattered through the anhydrite cap in general and through the matrix of the breccia of the specimen illustrated in Figure 20 make it seem probable that most of them are secondary. If it were possible to differentiate in this rock between calcite and dolomite, the dolomite might be found to be of a different character from the calcite and to have a more definite distribution in the bands; but so far the writer has not been able to make this differentiation. Carbonate crystals of the size of the larger ones in Figure 23 can be recognized easily on the polished face of the core, and by treating these with acid it is easy to prove that they are dominantly calcite. But there are also many small carbonate crystals, some of which are indicated in Figure 23, and it seems significant that these are rather numerous along the surfaces of division between bands, especially along the more clearly defined, more impure portions.

ABSENCE OF DETRITAL MINERALS

One important bit of evidence against the assumption of general sedimentary origin of the anhydrite cap rock is the fact that the residue left by the solution of the anhydrite and gypsum with hydrochloric acid does not seem to contain any detrital sand. It is of course quite conceivable that the basins in which the anhydrite may have been deposited were too large, that the currents in them were too sluggish, or that the cap rocks examined came from localities too near the centers of these basins for sand to have reached them. If further study reveals sand in some anhydrite caps and not in others, and differences in the prevailing size of the sand from different caps, it would pretty well prove the sedimentary origin of the anhydrite cap in general and might make it

possible to work out some of the boundaries of the basin or basins of deposition. In the sample from the Flood well, in Culberson County, Texas, sand is abundant and rather coarse; but the bedding in that core was much thinner than the bands in the parallel-banded cap rock, indicating differences in the conditions of accumulation of the two types of rock.

FORM OF THE TOP OF THE SALT MASS

Another feature which casts doubt on the assumption that the anhydrite of the cap was brought up as a bed of sedimentary anhydrite from depth is the supposed form of the top of the salt mass. Evidence is accumulating, from those domes in which enough drill holes have reached the salt, to give the basis for an opinion as to its form, that the top of the mass is quite flat. It seems obvious that such a surface could not result from intrusion of the salt mass, which would yield some sort of convex or irregular upper surface, so that if the salt mass is intrusive, a flat upper surface must be due to some later alteration. Solution by underground water is the explanation that at once suggests itself. If this upper surface of the salt is formed by solution, it is hard to conceive of a cap of anhydrite of sedimentary origin lying directly on it. Perhaps these difficulties cannot only be met, however; they may even serve to account for the brecciated character of the anhydrite cap; for the breccia fragments may be due either to collapse of the cap onto the dissolving salt mass, or they may have existed as included fragments in the dissolved salt. Under either alternative the matrix of the breccia fragments would be derived from solution and redeposition of part of the material of the original breccia. Stages in this process might also account for the parallel banding of the matrix anhydrite.

SUMMARY OF EVIDENCE REGARDING THE ORIGIN OF THE ANHYDRITE CAP

Although the possibility has been considered that the banding in the fine-grained breccia fragments and in the coarser-grained matrix may both be the product of sedimentation, the fragments are necessarily older than their matrix, and their banding may therefore have a different origin from that of the matrix. Three possible causes of the banding in both types of rock have been considered: (1) flowage

or shearing, (2) diffusion, and (3) sedimentation. No evidence from the banding of either type of rock favors origin by flowage or shearing. The microscopic evidence from the breccia fragments strongly favors a sedimentary origin of the material of those fragments, and the evidence from the larger features of those fragments, as it affords no clue in favor of origin by diffusion, is also taken to favor origin by sedimentation. The microscopic evidence from the banding in the coarser-grained matrix anhydrite is inconclusive, and the larger features of this banding somewhat favor origin by diffusion, though they can also be explained by assuming that they have resulted from sedimentary processes. Inasmuch as the evidence as to the origin of the anhydrite cap afforded by the banding of the coarse-grained matrix anhydrite does not affect the evidence afforded by the fine-grained breccia fragments, the origin of that cap from a bed of sedimentary anhydrite is indicated.

CONSIDERATIONS REGARDING THE PRESENCE OR ABSENCE OF ANHYDRITE CAPS ON SALT DOMES

If the anhydrite cap is, as suggested above, derived from a sedimentary bed of anhydrite brought up from depth by the salt which it overlay, it is reasonable to ask why it is absent on certain domes which are closely associated with others that have an anhydrite cap. Various possible explanations suggest themselves. One is that those salt plugs which lack anhydrite caps were formed in very sharp folds, which broke the anhydrite and gave the salt a clear passage through. Where that explanation fits the conditions observed the diameter of the salt plug should be small, at least in one direction. Or the anhydrite bed may have been thin and have broken open without very sharp folding. Another possibility is that some of the salt plugs without anhydrite caps were derived from a different salt bed, one perhaps very different in age from that which formed the source of the plugs that have anhydrite caps. The general field relations, such as lines of strike, should indicate whether there is any foundation for such an explanation. The Five Islands, none of which have anhydrite caps, are a group to which this explanation might apply. Another explanation, which would apparently also fit the Five Islands group, is that the anhydrite cap has come so near the

surface that it has been dissolved by surface waters. If that has happened, however, it seems as if there should be some residue from the solution. Anything that might be interpreted as such a residue is lacking, so far as known to the writer, from at least some of the Five Islands. Again, the salt plugs without anhydrite caps may be derived from a different part of the same salt bed, perhaps a part that lay nearer the edge of the basin of deposition or in some other locality where the overlying anhydrite bed was thin or lacking. But these are all guesses. What is needed is field observation of the relations of the salt plugs with and without anhydrite caps, and petrographic study of the material directly overlying the salt plugs that have no such caps.

THE CHARACTER AND ORIGIN OF THE CALCITE CAP

Some of the preceding observations afford a basis for a brief consideration of the "limestone" cap, as it is generally called, or the calcite cap, as the writer prefers to call it.

In the core from Sulphur Mine, as was shown above, the gypsum and anhydrite of the upper part of the gypsum-anhydrite cap are veined, penetrated, and in some portions almost completely replaced by calcite. The deposition of calcite, growing more intense toward the upper part of the gypsum-anhydrite cap, no doubt entirely replaced some of the upper portions of that cap and continued into the overlying sediments. It is probably in this way that the calcite cap originated, and it is on this interpretation of its origin that preference for the name calcite cap is based. The term "limestone" has come to mean, to geologists, a rock consisting dominantly of calcite of sedimentary origin. As the writer believes that the calcite of the cap is dominantly of secondary origin, though some of it may be of primary sedimentary origin, the term "limestone" seems misleading.

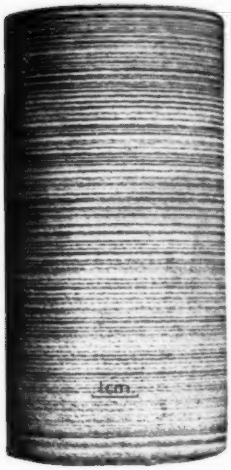
Reasons for considering the calcite cap essentially a replacement deposit are: (1) the evidences of replacement by calcite associated with veining by calcite seen in the gypsum of the Sulphur Mine core; (2) the evidence from the presence of sand, of calcified bedded sandstone fragments, and of fragments of calcite rocks that differ in texture and structure, some laminated, some homogeneous, that the

fragments in or between the vein portions are derived from sedimentary rock of different types. Some of these fragments are undoubtedly derived from the gypsum-anhydrite cap, but where calcification is complete, this fact is difficult to establish and, in any event, is not important in the general interpretation of the calcite cap.

Figures 25 to 28 and Figure 30 illustrate typical calcite cap rock, although these specimens have not been studied microscopically. Figures 25 and 30 show a type in which, it appears, calcite veining has taken place largely along bedding planes as well as across them. Anyone familiar with the marble from Winnfield, Louisiana, will recognize the resemblance between the two. The rock of Figure 26 is veined quite at random, probably because it was more massive than that of Figures 25 and 30, although it shows banding at an angle about like that in Figure 25. Figure 27 is of particular interest because it shows different stages of movement with brecciation and veining. Between the coarse undisturbed calcite veins, which evidently represent the last stage of veining, are masses of brecciated dark rock which themselves contain breccia fragments and veins of an earlier cycle of movement. Some of these breccia fragments containing smaller fragments can be seen at points marked *a* in Figure 27.

Figure 28 illustrates a type of sulphur-bearing calcite cap rock which seems to be characteristic of Hoskins Mound and in which the sulphur occurs as more or less definite bands in the calcite rock. Figure 26 also shows sulphur and gives evidence of its deposition inside of the calcite veins in the last stage of veining. Figure 29 shows breccia fragments of sulphur in a breccia of calcite cap rock. Other specimens give evidence of successive periods of sulphur deposition that followed successive periods of brecciation.

The evidence of successive periods of brecciation in the cap rock is offered because it has been suggested that these breccias might have been formed by collapse of the cap rock into caves occurring in it. Such caves are encountered in drilling. But it seems highly improbable that caves would characteristically form successively in the same place, so that material deposited at the bottom of one cave would later be dropped down into another one beneath. Further-



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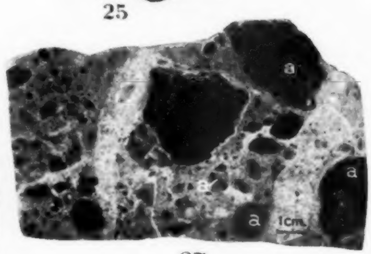

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FIG. 24.—Well-laminated sedimentary anhydrite

View of the outside of a core from 2,131 feet in the David Flood well No. 1, Gresham and McAlpine farm, Block 54, Sec. 42, School Lands, Culberson County, Texas. Received from Dr. J. A. Udden.

FIG. 25.—Coarse white calcite, veining and interbanded with a banded, fine-grained, black calcite rock.

Polished face of a core from 705 feet in well T26 of the Freeport Sulphur Company, at Hoskins Mound, Texas.

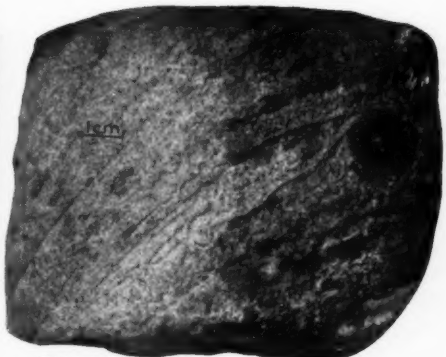
FIG. 26.—Massive, black, fine-grained calcite rock veined with coarse white calcite.

A vague and irregular banding, suggesting flowage, can be recognized. *s* marks occurrences of sulphur. *s's'* marks a thin vein, partly open, partly filled with sulphur. Polished face of a core from 1,379 feet in well 18 of the Freeport Sulphur Company, at Hoskins Mound, Texas.

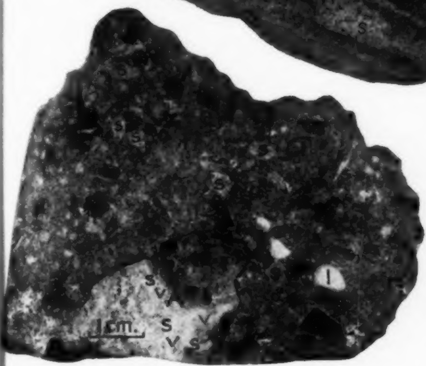
FIG. 27.—Breccia of calcite cap rock

a marks breccia fragments which themselves are made up of fragments apparently from an earlier stage of brecciation. Polished face of a core from 1,052 feet in well T 23 of the Freeport Sulphur Company, at Hoskins Mound, Texas.

28 A



28 B



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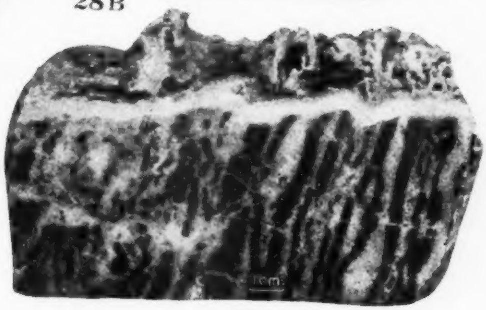

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FIG. 28.—Bands of sulphur in calcite cap rock

Two views of the same specimen, (A) the polished face, (B) the outside surface. In the polished face, the lighter portions are sulphur, as indicated, sporadically, by *s*. The sulphur occurs more or less in well-defined, roughly parallel bands which appear as the raised portions on the outside surface. On the polished face, these sulphur bands can be seen to be accompanied by thin seams of darker calcite, most of which sharply bound one edge of the sulphur bands. Core from 1,295 feet in well No. 2 of the Freeport Sulphur Company, at Hoskins Mound, Texas.

FIG. 29.—Brecciated calcite cap rock full of sulphur fragments

s marks a few of the sulphur fragments. *A* marks what is probably a single fragment in the present breccia, but made up of fragments from an earlier stage of brecciation and cut by a calcite and sulphur vein (*V* and *S*) which does not extend beyond the fragment. The boundary of *A* has been retouched in the illustration. *l* marks some of the breccia fragments of calcite rock. Polished face of a core from well 273 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

FIG. 30.—Similar to Figure 25 with more sharply defined bands

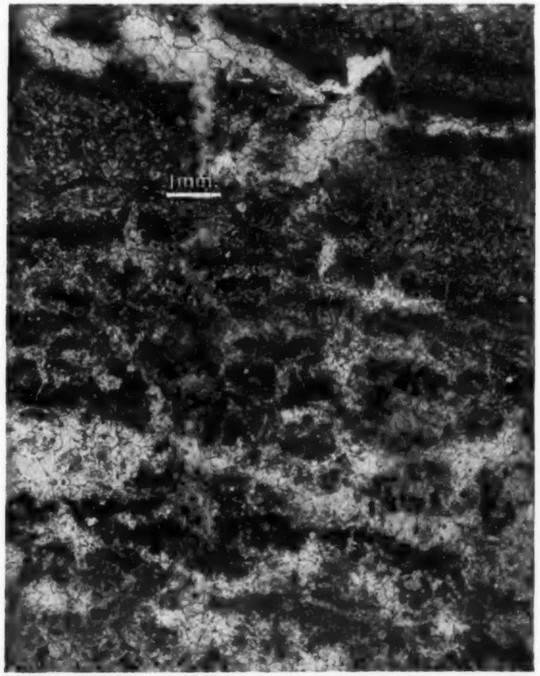
Polished face of a core, specimen 135 of the Texas Gulf Sulphur Company, from Big Hill, Matagorda County, Texas. At the top of the figure calcite-lined druses can be seen. The specimen is lying on its side.

more, it seems likely that a cave breccia would contain fewer relatively small fragments and that it would be cemented by coarse-vein calcite rather than by material similar to the breccia fragments. More probably these breccias are the result of crushing by upward movement of the salt plug or by faulting.

The microscopic character of calcite cap rock that is undoubtedly similar to that illustrated in Figures 25, 26, and 30, though represented by chips in which the larger relations could not be seen, is illustrated in Figures 31 and 32. Figure 31 illustrates a type of rock similar on a smaller scale to that of Figures 25 and 30. Vein calcite has penetrated all through a rock which originally was apparently parallel banded. The original rock, in its present condition also composed of calcite, is represented by the darker, less pure, and generally finer-grained portions. The specimen shown in Figure 32 is of particular interest because it includes, parallel to disturbed bands of calcite rock of various textures penetrated by vein calcite, irregular bands of quartz sand also in a calcite matrix. This obviously sedimentary material is 128 feet below the highest specimen of calcite cap and only 50 feet above the highest specimen of characteristic cap-rock anhydrite received from this well.

SOURCE OF THE SEDIMENTARY MATERIAL IN THE CALCITE CAP

One of the most interesting problems regarding the calcite cap is the source of the sedimentary rock in which the calcification has taken place. Calcification of sedimentary beds in place adjacent to the present cap seems to be pretty well established, so that there is good reason for assuming that some of the calcite cap originated near its present position. But if the intrusive origin of the salt plug is accepted, it seems reasonable to assume that some of the material of the calcite cap may have been derived from sedimentary beds encountered in depth by the salt plug in its upward passage. Indeed, on the basis of the intrusive theory, it seems pertinent to ask, as with the anhydrite, If there are no remnants of material of deep-seated origin, what has become of them? In general, the sedimentary material originating at greatest depth should of course occur in the deepest part of the calcite cap. If some of the calcite cap can be proved to



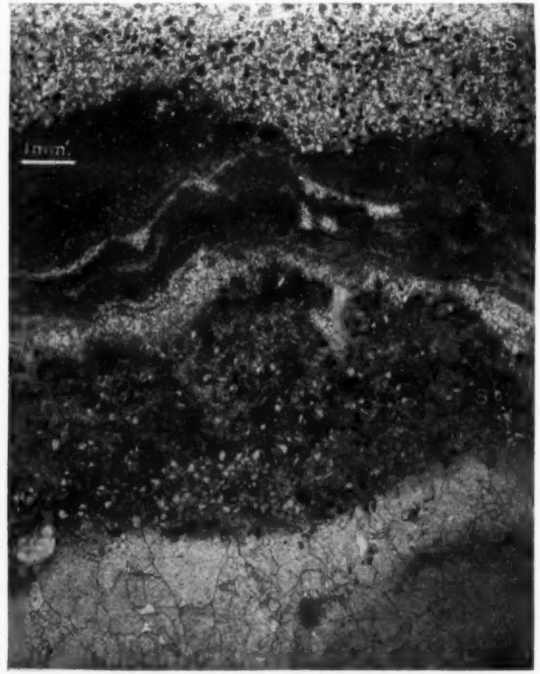


FIG. 31.—Thin section of calcite cap rock, showing penetration of a black-banded rock by calcite

All the rock is calcite, but the perfectly clear parts are apparently later than the impure to black parts which they vein and penetrate irregularly. From 947 to 948 feet in well 17 of the Texas Company, at Hoskins Mound, Texas.

FIG. 32.—Thin section of sandy calcite cap rock, showing definite banding of a sedimentary nature

ss marks more definitely sandy layers, though, presumably as a result of flowage, the distribution of sand is irregular and not limited to definite layers. From 1,036 to 1,037 feet in well 17 of the Texas Company, at Hoskins Mound, Texas.

come from great depths, the primary sedimentary origin of the anhydrite cap that underlies it would at the same time be proved.

The writer has no evidence contributing to the solution of this problem. Fossils, if there ever were any in the material from which the calcite cap was formed, are not likely to have survived the intense alteration that it has undergone. But there is a nice opportunity here, by using the sandy material in the cap, to see what can be done by mineralogic correlation. This line of attack offers many obstacles, but it seems the best available and if successful would afford valuable evidence on the whole problem of the origin of salt domes.

SOURCE OF THE CALCITE OF THE CALCITE CAP

The source of the calcite which, apparently by veining, cementation, and replacement, has formed the calcite cap is another problem on which little evidence is available from the writer's own observations. The occurrence of the calcite and sulphur in such intimate association above a mass of anhydrite and the abundance of hydrocarbons in the beds adjacent to most domes suggest the obvious idea that the calcite and sulphur are the products of reduction of the anhydrite by the hydrocarbons. Chemically this reaction is quite possible, as is pointed out below in the general statements on the chemistry of cap rock. That it is the reaction by which the calcite cap has actually formed is not proved. The calcite and sulphur bear all indications of having been introduced from outside along veins and planes of weakness and by penetration and replacement in the adjacent rock. Presumably the intense reaction between hydrocarbons and anhydrite would take place at the edge of the anhydrite-gypsum cap, and it is in the outer edge of the cap that sulphur and calcite are said generally to be most abundant. But this relation of calcite and sulphur to the cap is to be expected, whatever outside source they may have had, so that it proves little.

MINOR CHARACTERISTICS OF CAP ROCK

This paper attempts no discussion of features not considered essential to the interpretation of the origin of the cap rock. Among these minor features is the presence of sulphides, which are very common in the anhydrite cap, although in most specimens they occur in small

proportion. Another is the presence, in the gypsum-anhydrite cap, of carbonates of a stage apparently preceding the calcification that

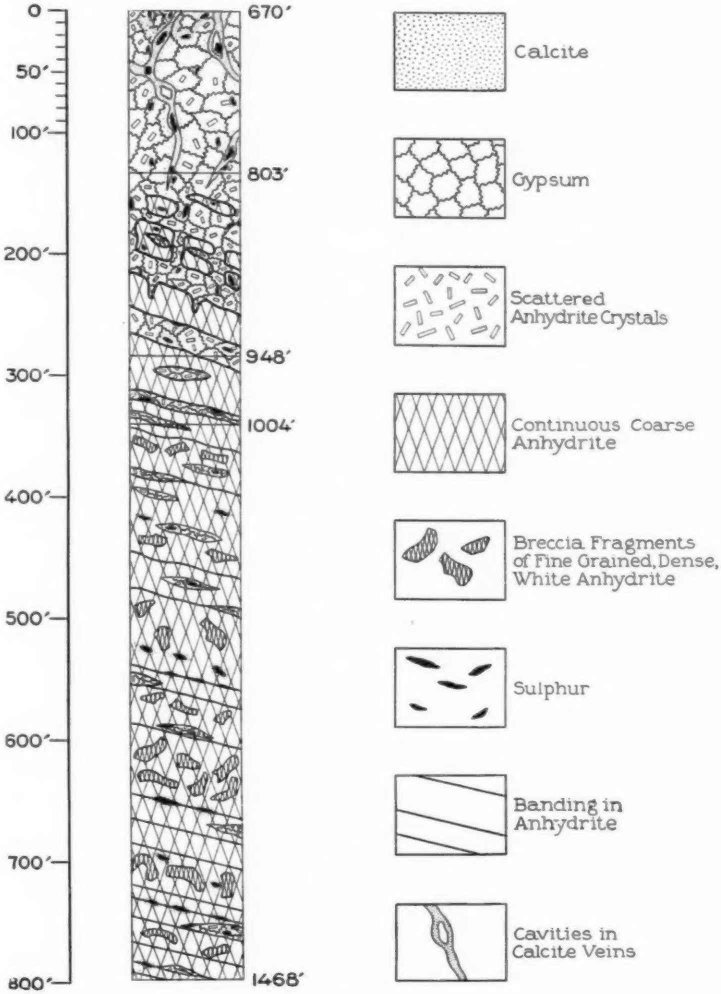


FIG. 33

produced the calcite cap. Calcite is, as might be expected, the most common of these carbonates, occurring characteristically in well-developed rhombohedra, many of which show growth stages. Dolomite is disseminated as crystals in the breccia fragments illustrated in Figures 20 and 21, but it appears to be scarce; the tradition that dolomite as a rock makes up some cap rocks seems to have no foundation in fact. In one specimen of anhydrite from the Davis Hill salt dome, disseminated crystals of brown sideritic carbonate were common, and in another, of unknown origin, similar crystals were disseminated in intimate association with a sulphide, presumably pyrite.

Other constituents of interest are barite and celestite, the sulphates of the less common alkaline earths barium and strontium, which were found in a number of specimens of the calcite cap.

Very nearly perfect doubly terminated quartz crystals appear to be present in all gypsum and anhydrite cap rock, as they were found in the residue of all specimens of this material dissolved in hydrochloric acid. In most of the rock they are too scattered and scarce to be found in thin sections. Most of them appear quite pure and clear and give no indication of having been derived by the growth of secondary quartz around an original detrital grain of quartz sand. According to Cayeux[1] such quartz crystals are characteristic of gypsum deposits.

Among certain peculiar features that are not discussed in detail in this paper, one of the most interesting and puzzling is the occurrence of large pieces of sandstone or of calcified sand in the midst of anhydrite, as illustrated in Figures 16, 17, and 19. Is this sedimentary sand that was deposited in the midst of sedimentary anhydrite; or did the anhydrite flow around sand or sandstone adjacent to it; or is it secondary anhydrite deposited from solution around the sand?

THE CHEMISTRY OF CAP ROCK

One of the chemists of the United States Geological Survey, Mr. R. C. Wells, when asked to discuss the possible chemical reactions involved in the origin of cap rock, pointed out that there are

[1] L. Cayeux, *Introduction a l'étude pétrographique des roches sédimentaires*, p. 196. Paris, 1916.

so many possible reactions that merely to list them would leave the solution of the problem little farther advanced. The geologist must obtain from field observation all possible evidence as to the reactions that seem to him likely to have taken place and then come to the chemist for guidance as to which of these reactions are possible, and which, under the particular circumstances, are the more probable.

The following simple statements, however, were obtained from Mr. Wells and are offered with his approval: (1) Hydrocarbons (oil, gas, and so on) from the sedimentary rocks reacting with anhydrite or gypsum might very well produce $CaCO_3$ and S or H_2S. In this way sulphur might be separated in depth and $CaCO_3$ removed. (2) Sulphur could go into solution by virtue of a number of reactions, especially at high temperatures—as organic sulphur-hydrocarbon compounds, for instance, or by reaction merely with water, yielding H_2S, H_2SO_4, SO_2, thionates, etc.—or it could be sublimed. (3) The separation of sulphur from H_2S is an oxidation process and would therefore probably depend on the migration of the solution carrying the H_2S to upper levels where it could be oxidized. In this way sulphur might be separated near the surface. (4) Metallic sulphides would be very likely to be formed by H_2S-bearing solutions passing through rocks that contained metallic oxides or metallic carbonates. (5) As the formation of sulphur in the upper zones is likely to depend on oxidizing conditions, the formation of sulphides might well precede that of sulphur in those zones. (6) It is quite possible that barium and strontium sulphates might, like calcium sulphate, be reduced and brought into solution by hydrocarbon-bearing waters, by which they might be transported to regions where sulphates were again in sufficient excess to redeposit them as sulphates. (7) The transformation of anhydrite into gypsum can take place at almost any temperature in the presence of pure water, but in the presence of sea water it could probably take place only at temperatures below 30° C. (80° F.), and in the presence of a saturated solution of NaCl only at somewhat lower temperatures. So far as observations go, it does not seem probable that the temperature of this transformation would be much influenced by pressure, but it obviously is much affected by the presence of dissolved salts.

According to observations by C. E. Van Orstrand, of the Geological Survey, this temperature of 30° would be reached at Damon Mound at a depth of about 900 feet.

In conclusion, it is worth while always to have in mind that different cap rocks or different parts of the same cap rock may have different origins. The evidently complicated history of any specimen of cap rock points that way. Keeping this possibility in mind may avoid some confusion and misunderstanding.

ACKNOWLEDGMENTS

Help in carrying on this investigation has been received from so many sources that it would be impossible to name them all. In fact, the writer cannot recall any company or individual approached that did not appear ready to contribute most generously, so far as business conditions would permit. This occasion is taken, therefore, to express on behalf of the United States Geological Survey, for which the help was of course primarily intended, sincere appreciation and gratitude. This help has come in the form not only of specimens and data but also in the liberal sharing of ideas, so that it would be hard to disentangle from the product what is the writer's own and what he has received from others, and he can merely acknowledge his debt in a general way here. It has been an inspiring example of the best sort of co-operation in a scientific investigation.

SUBSURFACE STRATIGRAPHY OF THE COASTAL PLAIN OF TEXAS AND LOUISIANA

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ABSTRACT

Careful study of micro-organisms which are abundant in many well samples from the Texas Gulf Coast has yielded information of importance concerning the seaward character of Tertiary formations which appear at the surface farther inland and has shown the presence of fossiliferous marine beds in parts of the section where no corresponding marine strata occur at the outcrop.

The Pleistocene and Recent deposits, and to a degree the Pliocene, have received scant study in well-sample investigations, for the oil of the Gulf Coast is mainly associated with Miocene and older rocks. Pliocene foraminiferal faunas resemble the Recent.

In the Miocene three distinct micro-faunas, distinguished by certain diagnostic genera, are recognized in many wells.

The Oligocene of Texas is represented in surface exposures only by unfossiliferous, non-marine sands and clays, but well sections show the presence of fossiliferous marine beds of Middle Oligocene age. Abundant Foraminifera are found in these strata, and it is readily possible to distinguish three zones. The Oligocene rests unconformably upon the Jackson, from which it differs both lithologically and in its fossils.

The upper part of the Eocene, including the Jackson and upper Claiborne beds, is encountered in many wells. The exposed parts of these formations are less fossiliferous and less complete than seaward sections revealed by well borings. The Jackson of Texas has been divided into three faunal zones. The Upper Claiborne has uniform and distinctive faunal characters where encountered in wells.

Detailed notes on the stratified rocks encountered in the salt domes of Texas are presented.

INTRODUCTION

Within the last three years the microscopic study of cores and bit samples taken from wells in the gulf coastal fields has made possible the determination of the occurrence and character of the Pliocene, Miocene, Oligocene, Jackson, and Claiborne deposits in this region. Not only has it been possible to recognize the formations, but we are now able to subdivide them on the basis of faunules whose stratigraphic sequence has been carefully determined. All this has been accomplished largely through the use of foraminifera, which, at least in this region, are found grouped into definite and distinct faunas which with training a paleontologist can readily recognize. In the beginning of this work an attempt was made to

use the macroscopic fossils as a basis of subdivisions, but the limit of the possibilities in the use of these forms has been expressed by Harris, who, after working over the exceptionally abundant fossils secured from the Galveston deep well, says that

> the fauna is so sparse between numbers 38 and 125 inclusive that it is unsafe to attempt to state just where in the Tertiary it should be placed. In fact, beds included between the depths 450 and 1,500 feet may not be Tertiary at all but Pleistocene. The undescribed and for the most part extinct species occurring between the depths 1,500 and 2,150 feet show conclusively that the beds penetrated are Tertiary in age.[1]

We have therefore turned to the microscopic forms and have been rewarded by results some of which are presented in this paper. This work should be supplemented by careful petrographic studies of the materials found, especially in formations which are largely non-fossiliferous, as the Fleming of the coastal region and the deposits drilled in southwest Texas.

The formations will be discussed separately in descending order as they would be encountered under drilling conditions.

I. PLIOCENE AND MIOCENE FORMATIONS

GENERAL DISCUSSION

In the microscopic study of well sections from the coastal belt of Texas and Louisiana, it has been found that the lithology and fauna of most of the formations encountered vary to such a degree from that of the standard section made from the outcrops that new lithological and paleontological rules had to be formulated for their subdivision. Whenever possible the old lithologic characters were used to suggest these subdivisions, but in the main they were the result of close observation and comparison of the sequence of materials secured from samples carefully taken from wells scattered throughout the area. The reason for this marked change in character between the formations as found in the wells and as seen at the outcrop is evident, since the late Tertiary and Quaternary beds are covered to the south by extensive overlaps which hide the changes naturally taking place along the seaward extension of these beds.

[1] *Fourth Ann. Rept. Geol. Surv. Texas*, p. 118.

Of the three youngest geological divisions encountered in the wells, the Miocene and Pliocene, especially the former, are the ones to which the closest attention has been given and on which the largest amount of data had been secured. Since oil is the object of all the wells drilled, and expense is an important factor of the drilling, samples are rarely secured from the Pleistocene and Recent formations. The Pliocene, as a rule, also received but scanty attention, and so it is only from the Miocene that we have been able to secure data which is comparatively adequate and on which we may base any general conclusions. Within the last year or two the Pliocene has received a little more attention than heretofore, but the Pleistocene and Recent materials are still usually omitted from the sections, not always because they are absent, but largely, probably, because of their close approximation to the outcrop descriptions already made. This discussion, therefore, is confined to the Miocene and Pliocene formations.

These formations have been roughly and rather arbitrarily separated on the basis of certain comparatively constant, lithologic, and faunal characteristics. As on the outcrop, however, no definite line can be drawn between them. For the sake of clarity we will here use the name Lafayette to represent the division found in the wells in southeastern Texas and in Louisiana, which we believe to be for the most part Pliocene in age; and Fleming for the lower division, in the same region, which is largely Miocene. A few diagnostic macroscopic fossils, vertebrate, and invertebrate which have occasionally been found in well samples have confirmed these age determinations. For southwest Texas, the terms Lapara, Lagarto, and Oakville will be used, since the strata in those sections are usually fairly similar to the outcropping formations bearing those names.

Within the coastal belt discussed in this paper, these formations vary somewhat, lithologically and faunally, from north to south and east to west. Roughly speaking, the Lafayette consists of a series of sands, clays, and conglomerates, usually light tan in color. The sands are generally highly polished and poorly sorted. Many worn lime nodules, often terra cotta in color, and chert pebbles are present. At some localities, usually near the present coast line,

gray sands with many shell fragments from *Ostrea*, *Rangia*, *Balanus*, and sometimes a few other brackish water species are found. These beds for the most part lack a microscopic fauna, but occasionally comparatively large secondary specimens of a variety of *Globigerina dubia* occur in abundance, and we sometimes find a few indigenous species of foraminifera which are closely allied generically and specifically to those which may be found along our shores today.

The Fleming beds are made up largely of the so-called gumbos and some fine-grained sandstones and sandy clays. At many localities the gumbos form the major portion of the formation, as at Pierce Junction, Humble, Blue Ridge, while elsewhere, as at Hull, the fine sands and sandy clays predominate. Where much gumbo is present we generally find it light tan and reddish brown in color in the upper portion and blue and blue green in the middle and lower portions, with sometimes a purplish red near the base. Generally, also, even when the section is largely composed of gumbo we find that the formation gradually becomes more sandy and often changes into fine sands and sandy clay in its lower portion. The sands are usually very fine, comparatively even-grained and light gray in color. Small white lime nodules and small aggregates of pyrite crystals are frequently present. Like the Lafayette, these beds are generally low in fossil content. Indigenous faunas are rare and when present show both by the fauna found and by the very local character of the beds that the seas of Fleming times were shallow, usually brackish water, narrow embayments of short duration and very limited extent. These incursions of the sea probably took place at slightly different intervals in different localities and were repeated several times in some regions. Usually, as would be expected, these marine invasions are more numerous, and occasionally show deeper water phases, in regions close to the present coast line. The Lower Fleming was the time of the most widespread submergence. At Stratton Ridge and Saratoga a fairly varied fauna of microscopic forms has been found in such beds. In the non-marine portion of the Fleming formation we frequently find small worn casts of foraminifera which are common to and characteristic of the Upper Cretaceous formations. These have been secondarily deposited here, just as re-worked Cretaceous *Gryphaeas*

and other forms are found redeposited in some of the outcropping Fleming beds.

In defining the formation names used in this portion of the paper it was stated that only the approximate age of the formations could be given. This statement should be qualified by noting that while some part of Pliocene time may be represented in the upper portion of our Fleming division, it is also possible that some equivalent of the Catahoula formation of Upper Oligocene time may also be represented at some localities in the lower portion of this division as at present delimited.

In southwest Texas the lithologic aspect of the upper formations found in the well sections is very similar to that of the outcrop. It is not necessary, therefore, to describe here their general characteristics. A very complete section of the Oakville formation on the outcrop was recently made by Applin and Reed, of the Rio Bravo Oil Company, and a microscopic study of the samples revealed the presence of many secondary Cretaceous foraminifera which occurred throughout the formation. At the base, near the Frio contact, a large number of forams, belonging to the family Astrorhizidae, were found. In the well sections the Oakville formation also contain many secondary foraminifera. Chara fruit cases and a few fresh-water species of ostracods are found occasionally in the upper portion of the formation.

The section made also included the Lapara and Lagarto formations, and from the middle portion of the former a few shallow marine species of foraminifera were secured as noted in the description of the marine fauna from that formation.

FAUNAS OF THE PLIOCENE

In the few instances in which the Pliocene beds contain indigenous foraminifera, the species found are very closely related to the ones which may be collected from the sands at Galveston beach at the present time. This is not surprising since Pliocene macroscopic fossils bear the same close relationship to Recent forms.

Marine Pliocene foraminiferal faunas have been reported from Stratton Ridge, Brazoria County, Terry Field, Orange County, Big Hill, Matagorda County, wildcats in Galveston County,

wildcats in Live Oak County (Middle Lapara), and outcrops of the Middle Lapara in Live Oak County. The forms generally found are *Rotalia beccarii* (Linn.) d'Orb., *Rotalia beccarii* n. var. *texana*

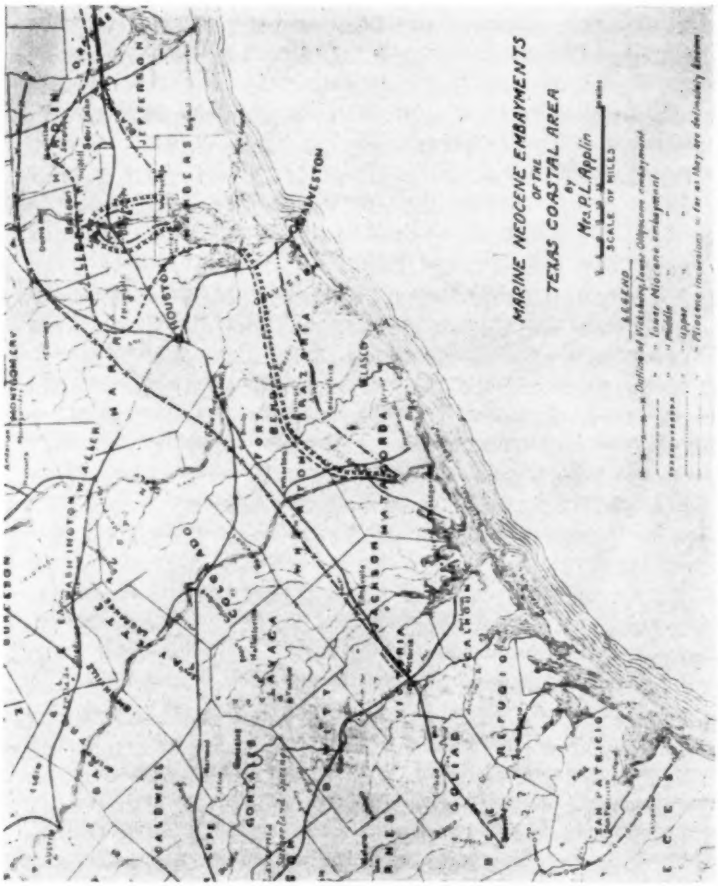


FIG. 1

(with highly ornamented sutures similar to those in the form figured by Cushman on Plate VI, *U. S. Geol. Surv. Bull. 676*), *Polystomella* n. sp. *galvestonensis* (near *craticula* var. Cushman, *ibid.*), *Quinqueloculina* (cf. *auberiana* d'Orb.).

FAUNAS OF THE MIOCENE

Three fairly well-defined faunas have been recognized in the rare marine phases of the Fleming formation. These have been named for the genus of foraminifera which dominates each. They are the *Rotalia* fauna, the *Truncatulina* fauna, and the *Globigerina* fauna. It must be understood, however, that although the Fleming fauna as a whole is characteristic and easily separable from the older faunas, the faunule subdivisions, unlike those of the Oligocene and Jackson formations, do not have a definite stratigraphic value, but indicate changes in depositional and bathymetric conditions only. This is due to the fact that the seas were generally very shallow and the species present few in number, and usually long-ranging forms which have the same stratigraphic value as the oyster among macroscopic forms. This accounts for the fact that the same fauna may recur at intervals in the formation.

"ROTALIA" FAUNA

The *Rotalia* fauna is the most common one. The localities from which we have recorded it are Barbers Hill, Chambers County; Stratton Ridge, Brazoria County; Mustang Mound, Brazoria County; several wildcats in Brazoria County; West Columbia, Brazoria County; Damond Mound, Brazoria County; Hoskins Mound, Brazoria County; Big Hill, Jefferson County; Shepherds Mound, Matagorda County; Markham, Matagorda County; Hull, Liberty County; South Dayton, Liberty County; wildcats in Hardin County; wildcats in Harris County; wildcats in Fort Bend County; Terry Field, Orange County; wildcats on Galveston Island.

At many localities *Rotalia beccarii* Linn. and its varieties are the most abundant forms found. *Polystomella* n. sp. *strattoni* is the next most common form, and the other species listed occur occasionally. A list of the species found in this faunule is as follows:

Rotalia beccarii (Linnaeus) d'Orbigny, several varieties

Polystomella n. sp. *strattoni* (nearest described species is *P. craticulata* [Fitchel and Moll]) d'Orbigny

Quinqueloculina auberiana d'Orbigny

Quinqueloculina seminula (Linnaeus) d'Orbigny

Polystomella n. sp. ? (nearest described species is *P. sibirica*) Goës

Amphistegina lessoni d'Orbigny

Polystomella striatopunctata (Fitchel and Moll) Parker and Jones
Nodosaria, probably n.sp. nearest to varieties of *subscalaria Cushman*

"TRUNCATULINA" FAUNA

The *Truncatulina* fauna is only rarely present and occurs most commonly in wells drilled close to the present coast line. It is generally found in the Upper Fleming near the Lafayette contact, but recurs in the Middle Fleming beds in some wells studied from Stratton Ridge and is present in the Lower Fleming in a wildcat drilled in Brazoria County. It has been reported from the following localities: South Dayton, Liberty County; Saratoga, Hardin County; Stratton Ridge, Brazoria County; wildcats in Brazoria, Matagorda, and in Galveston County.

The characteristic species present in this fauna are:

Truncatulina americana Cushman var. *strattoni* n. var.
Textularia espersoni n. sp.
Polystomella n. sp. *strattoni*
Rotalia beccarii, several varieties
Polystomella strattoni n. var. *brocki* (reticulated portions broader than in typical form)
Nonionina scapha n. var. *dumblei*
Textularia (probably n. sp. nearest to *tumidula* Cushman)
Globigerina cf. *bulloides*
Globigerina n. sp. *strattoni* (nearest to *bulloides* as figured by Cushman in *Prof. Pap. 128*, Plate XI, Fig. 6)
Polystomella poeyana d'Orbigny
Textularia agglutinans d'Orbigny
Quinqueloculina var. cf. *auberiana* d'Orbigny
Polymorphina n. sp. *strattoni* (general outline and arrangement of chambers like *P. regina* Brady but not striated)
Bolivina sp.
Textularia n. sp. *seaburni* (nearest to *panamensis* Cushman)
Textularia cf. *articulata* d'Orbigny
Textularia cf. *subhauerii* Cushman
Discorbis cf. *bertheloti* d'Orbigny

"GLOBIGERINA" FAUNA

The *Globigerina* fauna is also rare and, when present, generally occurs about 500 feet above the base of the formation. This fauna is best represented at Saratoga, Hardin County, although meager representations of it have been found in a few other regions, as

South Dayton, Liberty County; Shepherd Mott, Matagorda County; Markham Field, Matagorda County; West Columbia, Brazoria County (Texas Co. well); wildcat in Harris County; Sour Lake, Hardin County.

The genera and some of the species present in this fauna so closely resemble phases of the Taylor Marl fauna that Miss Ellisor, of the Humble Company, has considered it a very beautifully preserved, although re-worked Cretaceous fauna. The author, however, is firmly convinced that the forms found are indigenous, because of (1) the excellent state of their preservation and the fragile condition of the tests; (2) because the assemblage of species found, although close to the Taylor forms, varies, as will be shown from the accompanying list, in a very definite and marked manner from any Taylor assemblage; (3) because the lithology shows that the fauna was deposited in a near shore, finely sandy and argillaceous bed with many oyster shells (these now badly broken, probably in the process of coring) showing a marine or brackish water condition, which at least furnishes a possibility for the presence of indigenous foraminifera. The species present are:

**Truncatulina*[1] *dumblei* n. sp. This form is apparently identical to the form found in the Taylor formation of Texas, and previously supposed to be confined to that horizon. After a very careful study of the species as it is found in the Taylor marl and in this well section, the only difference noted was in the fact that the superior face of the fossil in the Cretaceous beds generally curves downward noticeably along the outer edge from a practically flat central area, while the Miocene forms generally retain the flat surface to the outer rim.

**Globigerina marginata d'Orbigny.* This species occurs some times in Taylor faunas in which the so-called *Pulvinulina rosetta* is a common and dominant form, and has been incorrectly lumped under that species in the rather generalized lists of Taylor faunas, awaiting a careful study of the species present. It differs, however, from the typical Taylor form in such a constant and very definite manner as to leave no question but that it is a distinct species. While it is only rarely present, and when present, scarce in the Taylor fauna, it is common and abundant in this horizon and the typical Taylor form is entirely absent.

**Frondicularia rugosa d'Orbigny.* This species is new and not present in any Taylor fauna of which the writer is aware.

Frondicularia augusta Nilsson var. Occasionally present in Taylor faunas.

Vaginulina strigillata Reuss. Occasionally present in Taylor faunas.

[1] An asterisk occurring before the name means "dominant."

**Vaginulina* n.sp.—nearest to *V. patens* Brady but differing so constantly and markedly from that form as to warrant a specific determination. Not present in the Taylor so far as we are aware.

Vaginulina n.sp. Broken fragment nearest to *V. bradyi* Cushman

Discorbis n.sp., resembling most closely Cushman's *Discorbis* sp. (*U. S. Nat. Mus. Bull. 100*, Vol. 4). Not present in the Taylor so far as we can ascertain.

Nodosaria n. sp. Closest to *pyrula* d'Orbigny var. *longi-costata* Cushman.

Nodosaria cf. *vertibralis* Batsch. Very probably a new species.

Globigerina cretacea var. *Saratogensis* n. var. Form close to the one figured by Flint as *Globigerina dubia*, but having a very definite and consistent arrangement of chambers and a mouth-opening similar to many Discorbis forms.

Textularia globulosa Reuss? var. This is like an elongated and more slender form of the common Cretaceous species.

Pulvinulina n.sp., closest to *P. punctulata* d'Orbigny in general aspect.

Cristellaria n.sp., most closely resembling some varieties of *C. orbicularis* d'Orbigny.

The species *Rotalia beccarii* Linnaeus var. and *Polystomella strattoni* n.sp., although not present at Saratoga are found associated with a few of these forms (the *Truncatulina* and *Globigerina marginata* most commonly) at some of the other localities mentioned.

FAUNAS OF THE MIOCENE OF LOUISIANA

Rotalia beccarii has been reported from a number of wells in southern Louisiana and we have one record of a wildcat well which contained an exceptionally varied and prolific fauna that is related to the *Truncatulina* fauna of the Texas domes and is found near the top of the Fleming formation. The fauna varies, however, to such a degree from any found in Texas that it seems advisable to list the most common species present.

There are two zones within a few feet of each other very probably resulting from a change in depositional conditions. In the upper zone the following species predominate:

Truncatulina americana Cushman var. *strattoni*, n. var.
Polystomella striato-punctata (Fitchel and Moll) n.var.
Rotalia beccarii (Linnaeus)
Bulimina cf. *marginata* d'Orbigny
Ehrenbergina trigona Goëss var. *braziliensis* Cushman
Textularia foliacia Cushman var. *reedi* n. var.
Polymorphina cf. *regina* Brady
Nonionina scapha (Fitchel and Moll) n. var.
Polystomella macella (Fitchel and Moll)

The lower zone is composed largely of two forms:
Textularia foliacia Cushman *reedi* var.
Amphistegina lessoni var.

One or more oil-producing horizons are present in the Fleming formation on all of the domes discussed except Stratton Ridge. The Pliocene also produces in Terry Field, Orange County, and at Big Hill, Jefferson County.

SECTIONS

Several representative sections of the Lafayette and Fleming are given below. These sections are the result of the study of a number of wells from each area represented and give a generalized and, as far as possible, characteristic description of the materials encountered. The beds are so lenticular and are so disturbed by faulting and other factors that only in a very broad manner can any uniformity in materials, colors, and thicknesses be recognized.

HUMBLE, HARRIS COUNTY

No samples of Pliocene or younger materials have been studied from this dome so far as we could ascertain. The highest sample reported on came from 550 feet, at which depth the Fleming was already present. A generalized section of the Fleming as it is expressed on this dome shows an upper zone mainly composed of brown and light-gray sandy and highly calcareous sticky clays which contain small lime nodules, some pyrite, and secondary foraminifera. This is followed by a zone of red and green gumbos which also carry the pyrite, lime nodules, and secondary Cretaceous foraminifera found in the upper division and a few oyster shells near the base. The lower zone carries purple gumbos at the top followed by gray and greenish-gray sands and sandy clays and light-green, non-calcareous gumbos. In addition to the secondary foraminifera which continue to appear, oyster-shell fragments and small gastropods and pelecypods have been found in the sands and sandy limes of this portion of the section. These fossils give the only indication of the presence of marine conditions on this dome during Miocene times. They indicate a shallow marine invasion of this area near the beginning of this period. No indigenous foraminiferal faunas are present.

PIERCE JUNCTION, HARRIS COUNTY

We have a record of one sample studied from this dome which is probably Pliocene in age. This is a dark-red gumbo, which leaves a washed residue of brown, uneven-grained sand, some quartz and chert pebbles, and a few lime nodules.

The upper portion of the Fleming is composed of red and reddish-brown

and light-gray sandy, calcareous gumbos which contain some pyrite and many lime nodules. In the central portion of the formation the light-gray sandy gumbos are most common with lenses of pink and brown and with a few layers of soft, chalky lime. Dark-gray, greenish-gray, and a varying amount of purple and brown gumbo is found in the lower portion of the formation, which becomes more sandy near the base. Only a few secondary forams and some chara fruit cases are found on this dome, and there are no fossils present which would indicate the presence of marine sediments.

The Batson section is very similar to this one. Re-worked foraminifera, however, are abundant in that field and a few pelecypod fragments were reported in one sample. Charas are present at various depths as in the Pierce Junction section.

HOCKLEY, HARRIS COUNTY

The highest samples studied from this dome came from about 250 feet, where the Fleming formation was already present. For about 600 feet below this depth gray sands make up the major portion of the material. Lime nodules and re-worked foraminifera are present. Tan, brown, red, and some green gumbos characterize the second division of the formation. A varying quantity of fine sand, lime nodules, some pyrite and re-worked foraminifera are found in the washed residue from these samples.

Green and gray-green shales and gumbos and some gray clays form the third division. A small amount of pyrite and a few re-worked foraminifera are occasionally present.

Below these beds gray clays and gumbos merge into gray argillaceous sands and sandstones which continue without a clear break into the Oligocene formation. These beds contain a high percentage of pyrite at times. No re-worked foraminifera and no indigenous fossils are present in them.

This dome, like Pierce Junction, was apparently not affected by any marine invasion during Fleming times.

BLUE RIDGE, FORT BEND COUNTY

No laboratory study of Pliocene materials from this dome has been made so far as we are aware. The upper portion of the Fleming here is generally composed of red and gray calcareous clays and a large amount of gray sandstone. The clays are sandy and carry many lime nodules and some pyrite. The sandstone is also calcareous and pyritic. One report records the presence of a few pelecypod shells and some lignitic material near the top of the formation.

These beds are followed by a long series of gray clays and some green gumbos and streaks of lime. The clays and gumbos are sandy and carry some pyrite and lime nodules. Re-worked Cretaceous foraminifera are commonly present and many aragonite prisms which possibly represent re-worked *Inoceramus* fragments. Some chara fruit cases have also been reported from these beds. Red and blue marly gumbos, a small amount of sand, and many thin lenses of limestone are present in the lower portion of the Fleming section on this dome.

At the base, one well shows a series of purplish marls and another light-gray marls and marly sandstones. These beds also carry lime nodules, pyrite, aragonite, and secondary foraminifera.

As on the Humble dome, only one very imperfect indication of the presence of a marine condition is found. As on that dome, also, no indigenous foraminifera are present and the pelecypods could not be identified. Unlike the former dome, however, the marine invasion took place at the end rather than at the beginning of the period. This fact should help to make clear the point regarding lack of uniformity in the time periods represented by the marine phases of the Fleming in the region covered by this report.

HULL, LIBERTY COUNTY

The materials included in the Fleming formation as it is found on this dome are more sandy than on the majority of the domes in this region. One well, in which a part of the section was apparently faulted out, was composed largely of gray and highly sandy clays which continued through about 1,500 feet of deposits. One hundred feet of this material in the upper portion of the sections contained 50 per cent of microscopically fine particles of volcanic glass. An average section of the Fleming here is made up at the top of about 1,000 feet of brown, reddish-brown, some gray and greenish-gray sandy, generally calcareous clays, the washed residue of which shows sand, lime nodules, some pyrite, and re-worked Cretaceous foraminifera. In the central portion of the section there are about 500 feet of sandy clays, usually light gray in color. The washed material is like that found in the upper samples. Below these beds we find about 500 feet of dark-gray and greenish-gray sand and sandy clays, pyrite and lime nodules and re-worked foraminifera are still present in the washed material, but oyster-shell fragments and some indigenous foraminifera (generally only *Rotalia beccarii*) are found at intervals. Some glauconite and a little mica are present in this division. In some sections a small amount of the dark, purplish gumbo has been reported. The samples show that very shallow-water marine conditions existed on this dome during early Miocene times, and that some volcanic activity took place in this general vicinity in the latter part of the period.

SOUTH DAYTON, LIBERTY COUNTY

Red and yellow streaked, tan and pinkish-tan gumbos and light-gray clays form the upper portion of the Fleming on this dome. The material remaining after lixiviation of the samples generally contains some fine, even-grained sand and lime nodules, secondary foraminifera, and occasionally pyrite, glauconite, and muscovite mica. A thin bed of shallow marine deposits is indicated by the presence of fish scales, shell fragments, and a few specimens of *Rotalia beccarii*.

Three other divisions of this formation have been made from paleontological and lithological evidence found in samples submitted from this dome.

Immediately below the beds described above we find about 500 feet of sedi-

ments consisting mainly of light-green clays and light-gray sands, a little chalk and shale. Secondary foraminifera are the only fossils present.

Below these beds there are about 500 feet of blue-gray gumbos and dark-gray "pepper and salt" sands. This division is introduced by a marine phase of the formation shown by the presence of the *Truncatulina* fauna. A non-marine interval of about 200 feet is followed by a poor representation of the *Anomalina* fauna. A second non-marine phase completes this division.

The fourth and basal member of the formation consists mainly of gray clays with a thick lens of chalk near the center of the division. Light-green and greenish-gray shales in the upper portion carry a *Rotalia* fauna which differs strikingly from the one found in the higher horizon. This marine phase is followed by a series of sands and clays which are either non-fossiliferous or contain only a few secondary foraminifera.

The foraminifera found in this section indicate the presence of four brief shallow marine invasions over at least a portion of this dome during Fleming times.

SARATOGA, HARDIN COUNTY

On this dome the Pleistocene formation includes about 250 feet of light-tan-colored, uneven-grained sands and light-brown and reddish-brown gumbos and sandy clays, which contain many chert pebbles, lime nodules (often terra cotta in color), and occasionally a few chara fruit cases.

We have assigned to the Pliocene the next 350 feet of material, mainly light-gray sands (probably re-worked Catahoula) and blue and green sandy gumbos, which leave a washed residue of uneven-grained, moderately coarse sand, lime nodules, quartz and chert pebbles, and a little pyrite. Materials similar to those found in the Pleistocene deposits.

The upper portion of the Fleming formation is composed of greenish-gray and blue-gray, highly calcareous gumbos which contain some lime nodules (white in color), pyrite, secondary Cretaceous foraminifera, and generally some fine, even-grained, light-gray sand. These beds are followed by others, similar in character, but usually light gray, brown, and purple in color. After a few hundred feet the green gumbos again return. They are more sandy than in the upper portion of the section, and we find that the sand content increases steadily as we approach the base of the formation. There is no change in the washed residue from that found in the higher samples except the increase in the sand content just mentioned, and in the presence of many oyster-shell fragments and of a large and well-preserved fauna of indigenous foraminifera (our *Anomalina* zone) the description of which has been given earlier under the discussion of that zone. This fauna is found from about 200 to 100 feet above the base of the formation. On certain portions of this dome, some of the early wells drilled encountered a thin horizon of macroscopic fossils which were apparently deposited in early Miocene times. The presence of these fossils and of the foraminiferal fauna discussed would seem to indicate that the early

Miocene marine deposits of this dome were laid down in somewhat deeper waters than those generally present at that time in the gulf coastal area.

The Sour Lake section is almost identical to this one, both lithologically and faunally.

TERRY FIELD, ORANGE COUNTY

This field is unique in the large amount of Pliocene material present. A representative section shows over 3,000 feet of beds which are assigned to this formation. Gray sandstones with some gray clays and lenses of limestone and colored clays are the characteristic material found. Some pyrite and lime nodules are present, and near the base, shell fragments, *Potamides matsoni*, *Mulinia lateralis*, and *Rangia cuneata* have been reported.

Medium-gray and bluish-gray clays and argillaceous sands which contain many re-worked Cretaceous foraminifera form the upper portion of the Fleming beds in this field.

Red, green, brownish-gray, and some dark-gray clays become important about 1,000 feet below the introduction of the formation. These also contain re-worked Cretaceous foraminifera, lime nodules, and one or more beds in which *Rotalia beccarii* have been found.

Dark-gray clays are common in the basal portion of the section. Re-worked foraminifera continue to appear, and shell fragments and lime nodules are common.

BARBERS HILL, CHAMBERS COUNTY

About 500 feet of pinkish-tan sands, some gray sands, and blue-green and brown gumbos reported from some wells on this dome have been tentatively placed in the Pliocene formation. A few worn fragments of pelecypod shells and one horizon of foraminifera belonging to the family Astrorhizidae were found in these beds. No secondary Cretaceous forms were present. The sands were worn and uneven-grained. Some fine gravel was noted.

The youngest Fleming beds are represented by about 1,000 feet of green and bluish-green sandy marl, with thin lenses of white lime and a small amount of light-gray sand at the base. Lime nodules and re-worked foraminifera occur frequently in this material.

The next division shows red and blue marls in the upper portion with light-gray sands, greenish marls, and occasional lenses of red marl in the lower portion. The material is generally somewhat sandy, and lime nodules, pyrite, and secondary foraminifera are frequently present. A few chara fruit cases were found.

The oldest division is composed of alternating beds of gray sand and red and purple marls with some light-brown marls near the base. Four clearly marked beds of shallow marine deposits were reported as occurring at intervals of about 200 feet. These beds contain ostraceods, oyster shells, fragments of other pelecypods, and the *Rotalia* fauna. Re-worked Cretaceous foraminifera are also present occasionally in all of this material. A few chara fruit cases were

found in the basal portion of the formation. One sample of volcanic ash was also noted.

MARKHAM, MATAGORDA COUNTY

Light-gray marly sandstones and blue calcareous clays are prominent in upper portion of the Fleming in this field. Pyrite, aragonite, and secondary Cretaceous foraminifera are found in the material washed from the samples.

After about 500 feet of these beds red and blue marls appear. In addition to the residue materials found in the upper samples these beds sometimes contain oyster-shell fragments, chara fruit cases, and *Rotalia beccarii.*

The next division is largely made up of light bluish-gray marl, and foraminifera (usually *Rotalia beccarii* and varieties) are found almost continuously throughout these beds. The *Anomalina* fauna which is represented by a few species is present near the base of this division. Re-worked foraminifera are common and chara fruit cases are reported occasionally.

Very light-gray and some reddish marls form the basal section. These beds contain fossils, re-worked foraminifera, pyrite, and some lime nodules like those found in the beds just above.

The fossil evidence given above indicates that conditions of shallow-water marine deposition began here in Lower Miocene time and continued throughout the greater portion of the period. The absence of indigenous fossils in the uppermost portion of the section may indicate that there was a withdrawal of the sea in Upper Fleming times, which may have been brought about by an uplift of this domal region.

WEST COLUMBIA, BRAZORIA COUNTY

The Pliocene is reported as coming within 500 feet of the surface on this dome and no samples were kept.

The upper 1,000 feet of the Fleming is mainly composed of gray sands and sandy marls with some lenses of red gumbo which becomes the dominating material near the base. Red and blue gumbos make up the next 1,000 feet of Fleming beds, the blues predominating in the lower portion. There is a great deal of white lime present in the blue gumbos and some lenses of hard sand. At the base of this phase of the section, purplish and red gumbos come in.

At the bottom of the Fleming just above the Oligocene contact there is a thin streak of light brownish-tan gumbo from 10 to 30 feet thick, which is an excellent horizon-marker in the southeastern portion of the field, but is absent in the north and west sections. In the lower portion of the section a number of sand lenses are present which thin and thicken from well to well. Pyrite, lime nodules, and re-worked Cretaceous foraminifera are usually found throughout the major portion of the material. Two well-defined oyster-shell beds are present, one about 100 feet above the base of the formation and the other at about 300 feet. Description of samples, however, show oyster-shell fragments, indigenous foraminifera, chara fruit cases, and ostracods occurring almost continuously throughout the entire section. The *Rotalia* fauna occurs many

times and the *Anomalina* fauna is found in some sections near the base of the formation. Two lignite beds have been reported, one from the base and the other from the upper portion of the formation. The presence of so much marine material seems to indicate that this dome was in a state of shallow submergence throughout practically all of Fleming time.

DAMON MOUND, BRAZORIA COUNTY

The upper portion of the Fleming on this dome shows reddish-brown gumbos dominating, with some gray and bluish-gray also present. This material is generally sandy and contains lime nodules, some pyrite, and many secondary foraminifera.

Light-bluish and greenish-gray gumbos are most common in the central portion of the formation. These also contain lime nodules, pyrite, and secondary foraminifera, and in addition, chara fruit cases, oyster-shell fragments, and varieties of *Rotalia beccarii* appear at intervals throughout these beds.

In the lower portion of the formation the bluish- and greenish-gray gumbos continue, but no indigenous fossil material is present. One or more hard beds of sandstone are often found near the base, and some light-gray marl is also present, which contains oyster shells, fragments of other pelecypods, and a *Rotalia* fauna which includes a large number of *Polystomellas*.

This record shows that there was a shallow marine embayment over the area covered by this dome in early Fleming times, and that after an interval, the sea returned. This second invasion probably occurred in Middle Fleming and took the form of a series of very shallow water incursions, each of which lasted for only a brief time.

WILDCAT ON GALVESTON ISLAND

About 1,800 feet was assigned to the Pliocene in this section. These beds consist mainly of gray and brownish-gray clays and argillaceous sands. Shell fragments are common, among which *Rangia cuneata* was recognized from several depths. *Rotalia beccarii* (Pliocene variety) was also frequently present.

The upper section of the Fleming is made up of gray and greenish-gray sandy clays, with occasional lenses of deep-red gumbo in the lower portion. Shell fragments, *Rotalia beccarii*, and re-worked Cretaceous foraminifera are present in nearly all of the samples submitted, and two phases of the *Truncatulina* fauna are present: one near the top and the other near the base of this division. The foraminifera found in the faunas just mentioned are abundant and varied in genera and species and probably represent a comparatively deep and quiet water condition of deposition.

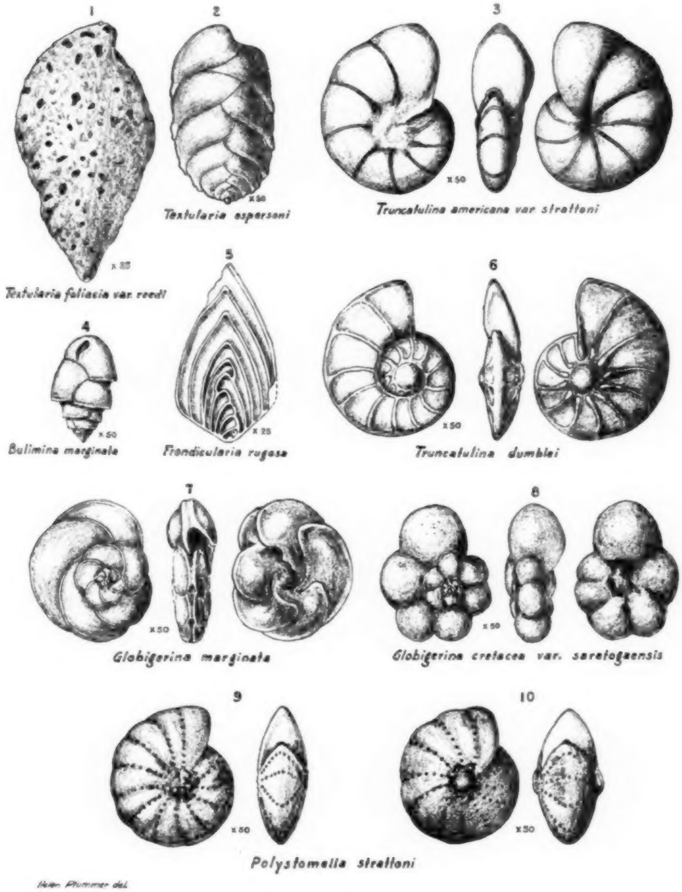
The lower division consists of gray and bluish-gray sandy clays and some red-brown gumbos. Re-worked Cretaceous foraminifera are the only fossils found.

The well did not reach the Oligocene, and the lower portion of the section is therefore unknown.

SOUTHERN LOUISIANA

Only a small amount of information regarding the Miocene and Pliocene subsurface conditions in this state is available. Lithologically and faunally the formations are apparently very similar to those of the same age in the Texas gulf coastal region. Gray and greenish-gray sands and sandy clays and a small amount of red clay make up the major portion of the Fleming sediments. Nodules of pyrite and of lime, re-worked Cretaceous foraminifera, occasional oyster-shell fragments, and sometimes a few other shallow or brackish-water genera of bivalves are found in the washed materials. Infrequently indigenous foraminifera are present. The *Rotalia* fauna is most common, but a very large and varied *Truncatulina* fauna has been found in the upper portion of these beds as noted under the description of faunas in this paper. A large Miocene fauna of macroscopic invertebrate fossils was also found in the same region.

The Pliocene consists mainly of tan-colored sands and clays with some brackish-water marine phases which are generally composed of fine, sandy gray marls carrying a few macroscopic fossils (*Rangia cuneata* and *Mulina lateralis* most commonly). *Rotalia beccarii* and sometimes a few other indigenous shallow-water foraminifera also occur. As in Texas, the sands are well worn and poorly sorted, and chert pebbles are frequently abundant.


1
2
3
x 50
Textularia espersoni
x 50
Truncatulina americana var strattoni
x 25
Textularia foliacia var. reedi
5
6
4
x 50
Bulimina marginata
x 25
Frondicularia rugosa
x 50
Truncatulina dumblei
7
8
x 50
Globigerina marginata
x 50
Globigerina cretacea var. saratogaensis
9
10
x 50
x 50
Polystomella strattoni
Helen Plummer del.

DESCRIPTION OF FIGURED SPECIES

In the hope of making this paper more valuable and useful to the economic micropaleontologist, we have thought it advisable to figure some of the forms which are most commonly encountered in the formations of the Gulf Coastal regions of Texas and Louisiana, and are either not figured or not clearly defined in papers on the subject of Foramnifera now readily available. These figures are from the Miocene and Pliocene formations only. We regret that it is impossible, at this time, to figure those from the Oligocene and Jackson also. *Rotalia beccarii*, a very common form, and a few other species which are also common have not been included in our plate because they have been well figured in a number of American publications on Foraminifera, and should, therefore, be readily recognized.

Family TEXTULARIDAE

Genus TEXTULARIA Defrance (1824)

Textularia espersoni n. sp. Applin

Plate 3, Figure 2

Test moderately large, short and broad, compressed. Thickest in the central portion, thinning rapidly to the edge, which is clearly marked and serrate. The suture lines bend down sharply at the outer edge and make that end of each chamber narrow and pointed. They are sometimes even produced into a small spine at the extremity. Chambers numerous, broad, and low. Early chambers increasing very rapidly in breadth, latter chambers very slowly. Walls arenaceous, smoothly finished. Aperture a well-arched opening at the base of the last-formed chamber.

Type specimen No. 1, laboratory collection of Rio Bravo Oil Company, Houston, Texas. From Esperson well, Brownsville, Texas, at 2,850 feet.

Textularia foliacia Heron-Allen and Earland var. *reedi* n. var. Applin

Plate 3, Figure 1

A species very close to the one described by Heron-Allen and Earland as *T. foliacia* occurs abundantly in certain marine phases of the Upper Miocene of southern Louisiana. Our variety differs from the species in the breadth of the chambers, which are narrower and more numerous and increase more slowly in size than in the typical form; in the suture lines, which are more nearly horizontal to the test and are poorly defined; and in the walls, which are more finely arenaceous. The variety is named in honor of Mr. Warren B. Reed, who discovered the form.

Type specimen No. 2, laboratory collection of Rio Bravo Oil Company, Houston, Texas. From Avoca No. 1 well, Avoca Island, Louisiana, at 1,105 feet.

Subfamily BULIMINAE

Genus BULIMINA D'Orbigny (1826)

Bulimina marginata D'Orbigny

Plate 3, Figure 4

A form apparently belonging to this species is found abundantly in some of the upper marine Miocene phases of Louisiana. The specimens studied have the edge only slightly crenulated, and the sutures are very deep. These two features would seem to separate our form from those figured in many of the European publications in which it is discussed, but would not exclude it from the species as described and figured by Cushman in the *U. S. Nat. Mus. Bull. 71*, Part 2, p. 83, Fig. 136.

Figured specimen No. 3, laboratory collection of Rio Bravo Oil Company, Houston, Texas. From Avoca No. 1 well, Avoca Island, Louisiana, at 1,097 feet.

Family GLOBIGERINIDAE

Genus GLOBIGERINA D'Orbigny (1826)

Globigerina marginata D'Orbigny

Plate 3, Figure 7

No description of this form was available, but the figures studied from the *Journal of the Royal Microscopical Society*, Part 4, 1910, Plate 9, Figures 1, 2, 3, seem to show that our specimens are at least very close to the form described by D'Orbigny under this name. We have figured it here because the publications in which it is figured are not easily available and because further study may show that our form is a variety of the described species.

Figured specimen No. 4, laboratory collection of Rio Bravo Oil Company, Houston, Texas. From Rio Bravo Oil Company well B-83, Saratoga, Hardin County, Texas, at 1,898–1,907 feet.

Globigerina cretacea D'Orbigny var. *saratogaensis* n. var. Applin

Plate 3, Figure 8

Test nautiloid, somewhat compressed. All chambers visible from above, only those of the last-formed coil visible from below. About six chambers in the last coil. Chambers increasing gradually in size, sometimes slightly carinated at the periphery. Walls smooth. Aperture at the inner end of the chamber near the umbilical cavity. The regularity of the coiling and of the graduated size of the chambers, and the tendency for the form to develop a carinated rim, has led us to give our specimens a varietal name by which they may be distinguished from other members of the species not characterised by these features.

Type specimen No. 5, laboratory collection of Rio Bravo Oil Company,

Houston, Texas. From Rio Bravo Oil Company well B-83, Saratoga, Hardin County, Texas, at 1,898–1,907 feet.

GEnus FRONDICULARIA DeFrance (1824)

Frondicularia rugosa D'Orbigny

Plate 3, Figure 5

The description of this species was not available for study, but the figure given in *Journal of the Royal Microscopical Society*, Part 4, 1910, Plate 8, Figure 7, is so like our form that we figure it here under that name. The only difference noted was in the shape of the test, which is more lanceolate in the Texas Miocene form.

Figured specimen No. 6, laboratory collection of Rio Bravo Oil Company, Houston Texas. From Rio Bravo Oil Company well B-83, Saratoga, Hardin County, Texas, 1,898–1,907 feet.

TRUNCATULINA D'Orbigny (1826)

Truncatulina americana Cushman var. *strattoni* n. var. Applin

Plate 3, Figure 3

This species is frequently seen in the Upper Miocene formation found in wells drilled in the coastal area of Texas and Louisiana. It differs constantly in certain features from the specimens belonging to this species which occur in the Oligocene formation in the same region, and is therefore, for clarity, described and figured here as a new variety of Cushman's form. The Oligocene forms are more circular in outline and lack the broad, flattened, lip-like projection of shell material which characteristically extends from the inner end of the chamber out over the umbilical region on the ventral face of the Texas and Louisiana forms. The mouth opening is an arched opening at the ventral margin of the chamber.

Type specimen No. 7, laboratory collection of Rio Bravo Oil Company, Houston, Texas. From Avoca No. 1 well, Avoca Island, Louisiana, at 1,097 feet.

Truncatulina dumblei n. sp. Applin

Plate 3, Figure 6

Test free, compressed, dorsal side flat to slightly convex, ventral side moderately convex, peripheral margin sharp. Chambers numerous, about twelve in the last-formed coil, outlined by a heavy band of clear shell material above and below. Central region above and umbilical region below filled with a button-shaped mass of clear shell material. Walls smooth, finely punctate. Aperture a narrow slit at the inner margin of the chamber.

Type figured No. 8, laboratory collection of Rio Bravo Oil Company, Houston, Texas. From Rio Bravo Oil Company well B-83, Saratoga, Hardin County, Texas, 1,898–1,907 feet.

Polystomella strattoni n. sp. Applin

Plate 3, Figures 9 and 10

Forms similar to the one shown here have been figured under the specific name of *P. striata-punctata* and *P. subnodosa*. In fact, the large number of dissimilar species which have been described under the former name is so confusing that we have thought it best to figure our species in this paper; and because our form differs in certain particulars from all of the descriptions available, and because the features by which our form may be recognized are persistent in all of the forms studied from the Miocene of the area covered by this report, we have here described it under a new specific name.

Test equally biconvex, about twelve to fourteen chambers in the last-formed coil, periphery narrowly rounded but not keeled, slightly lobulated, umbilical region flattened to slightly depressed, filled with clear shell material. Septal lines slightly depressed, evenly and narrowly bridged by small retral processes. Aperture a narrow slit at the base of the apertural face of the chamber.

After *Rotalia beccarii*, this is the most common species of the marine phase of the Miocene of Texas. In the Upper Miocene it is sometimes found associated with the species which characterizes the marine Pliocene of this area—a form similar to the one figured by Cushman, U. S. Geological Survey, in *Bull. 676*, Plate 8, Figure 6, as *Polystomella craticulata* var. In the Upper Miocene, *P. strattoni* is generally more globose in shape, and the chambers are more numerous. Two figures are shown to indicate the possible extremes of this form.

Type figured No. 8, Figure 10, laboratory collection of Rio Bravo Oil Company, Houston, Texas. From Seaburn No. 3 well, Roxana Petroleum Company, Stratton Ridge, Brazoria County, Texas.

Co-type No. 9, Figure 9, laboratory collection of Rio Bravo Oil Company, Houston, Texas. From Perry No. 1 well, Associated Oil Company, Stratton Ridge, Brazoria County, Texas.

Because of the limited space and time allotted to this portion of the paper, no synonomy has been given. We are indebted to Mrs. Helen Plummer, who very kindly consented to make the drawings for the plate accompanying these descriptions.

II. THE OLIGOCENE

INTRODUCTION

The outcropping Oligocene deposits in Texas are Upper Oligocene in age. These deposits are non-marine in origin and consist of beds of non-calcareous sands and sandstones, of sandy clays, and of

yellowish-green non-calcareous unctuous clays carrying calcareous nodules. The sands are composed mainly of coarse to medium-size angular, transparent quartz grains with some black chert or jasper. A characteristic feature is the quartzitic sandstone with porcelaneous cement. These beds lie below the Miocene and rest unconformably upon the Jackson.

No marine Oligocene, as far as known, outcrops in Texas. However, from our study of well samples we find that marine Oligocene does exist in Texas. Well sections show a fossiliferous formation resting unconformably upon the Jackson and lying below beds comparable to the outcropping non-fossiliferous Upper Oligocene. The presence of *Heterostegina antillea*, Cushman in the marine Oligocene beds of Texas, correlates these beds with the Antiqua formation of the West Indies, the type locality[1] of the Middle Oligocene, in which this species of Foraminifera is the key fossil. Some of the smaller Foraminifera of the Texas Oligocene are common to the Vicksburg group of Mississippi and Alabama. From the Jackson formation these Middle Oligocene sediments differ both paleontologically and lithologically.

LITHOLOGY

The lithology of the Texas Oligocene is variable, including limestones, sandstones, sandy clays and shaly clays. In the wells near the outcrop of the Catahoula or Upper Oligocene there is a series of non-marine clays and sands identical in character with the outcropping beds. But in a seaward direction the beds occupying the same stratigraphic position, that is, below the characteristic Miocene clays and above the Middle Oligocene, become less distinctive. The characteristic yellowish-green, non-calcareous clays are replaced by gray calcareous and non-calcareous sandy clays and clayey sands. The sands contain polished grains of transparent quartz with some black chert. These beds are correlated with the Upper Oligocene.

The lithology of the Middle Oligocene, as shown in the detailed sections, include sands, sandy clays, shaly clays, and limestones. The colors range through shades of gray and green.

[1] T. W. Vaughan, "Geology and Paleontology of the Canal Zone," *U. S. Nat. Mus., Bull. 103*, p. 203.

FOSSILS

The fossils present in the Oligocene include a few gastropods, pelecypods, bryozoans, and corals. These are very scarce and poorly preserved; consequently, they have not proved satisfactory for subsurface correlation. A wealth of Foraminifera is found in the cores and bit samples from wells, and upon these Foraminifera dedependence is placed both for correlation and age determinations. A few of the Foraminifera found in the Oligocene sediments are found also in the Jackson and Miocene. A comparison of specimens reveals that many species generally considered to be of wide range differ sufficiently to justify differentiation into new species. This is especially true for the genera *Cristellaria* and *Textularia*. Much work is needed on the reclassification of the Foraminifera.

On the basis of foraminiferal faunules the fossiliferous Oligocene can be divided into three zones, which we have called the *Discorbis* zone, the *Heterostegina* zone, and the *Marginulina* zone.

The following lists of Foraminifera in three zones show that there are many forms common to all three zones, while others are restricted. The names of the zones were given on the basis of the most characteristic fossils present in each.

MIDDLE OLIGOCENE

"Discorbis" Zone

Textulariidae:
- *Textularia gramen* D'Orbigny
- *Bolivina punctata* D'Orbigny

Lagenidae:
- *Cristellaria* cf. *vaughanii* Cushman

Globigerinidae:
- *Globigerina bulloides* D'Orbigny

Rotaliidae:
- *Discorbis vilardeboana* D'Orbigny
- *Pulvinulina texana* Ellisor nov. sp.
- *Pulvinulina humblei* Ellisor nov. sp.
- *Truncatulina floridana* Cushman
- *Truncatulina americana* Cushman
- *Siphonina advena* Cushman

Nummulitidae:
- *Nonionina pratti* Ellisor nov. sp.
- *Nonionina scapha* (Fichtel and Moll) Parker and Jones

Nonionina hooki Ellisor nov. sp.
Amphistegina lessonii D'Orbigny
Polystomella striatopunctata (Fichtel and Moll) Parker and Jones

"Heterostegina" Zone

Textulariidae:
- *Textularia concava* (Karrer) Brady
- *Textularia gramen* D'Orbigny var.

Lagenidae:
- *Polymorphina byramensis* Cushman

Globigerinidae:
- *Globigerina sacculifera* Brady
- *Globigerina bulloides* D'Orbigny

Rotaliidae:
- *Rotalia beccarii* (Linne) D'Orbigny
- *Pulvinulina texana* Ellisor nov. sp.
- *Siphonina advena* Cushman
- *Truncatulina texana* Ellisor nov. sp.

Nummulitidae:
- *Heterostegina antillea* Cushman
- *Amphistegina lessonii* D'Orbigny
- *Amphistegina lessonii* var. *texana* Ellisor nov. var.
- *Nonionina pratti* Ellisor nov. sp.
- *Nonionina scapha* (Fichtel and Moll) Parker and Jones
- *Nonionina boueana* D'Orbigny
- *Polystomella texana* Ellisor nov. sp.
- *Polystomella sagra* D'Orbigny
- *Polystomella subnodosa* (Muenster) Reuss

Miliolidae:
- *Quinqueloculina seminulum* (Linne) D'Orbigny
- *Quinqueloculina crassa* D'Orbigny var.
- *Quinqueloculina venusta* Karrer

"Heterostegina" Zone

CLAY

Textulariidae:
- *Textularia gramen* D'Orbigny
- *Textularia* cf. *agglutinans* D'Orbigny
- *Bolivina* cf. *dilatata* Reuss
- *Virgulina* cf. *schreibersiana* Czjzek

Lagenidae:
- *Polymorphina byramensis* Cushman
- *Cristellaria vicksburgensis* Cushman
- *Cristellaria rotulata* (Lamarck) D'Orbigny

Cristellaria submamilligera Cushman
Cristellaria americana Cushman
Uvigerina pygmaea D'Orbigny

Globigerinidae:
Globigerina bulloides D'Orbigny
Globigerina sacculifera Brady

Rotaliidae:
Pulvinulina humblei Ellisor nov. sp.
Pulvinulina texana Ellisor nov. sp.
Pulvinulina texana var. *strattonensis* Ellisor nov. var.
Pulvinulina sagra (D'Orbigny) Cushman
Rotalia vicksburgensis Cushman
Siphonina advena Cushman
Discorbis velardeboana D'Orbigny
Truncatulina texana Ellisor nov. sp.

Nummulitidae:
Heterostegina antillea Cushman
Amphistegina lessonii D'Orbigny
Amphistegina lessonii var. *texana* Ellisor nov. var.
Nonionina pratti Ellisor nov. sp.
Nonionina boueana D'Orbigny
Nonionina scapha (Fichtel and Moll) Parker and Jones
Nonionina advena Cushman
Lypidocyclina sp.
Polystomella sagra D'Orbigny
Polystomella striatopunctata Parker & Jones

Miliolidae:
Quinqueloculina seminulum D'Orbigny
Quinqueloculina lamarckiana D'Orbigny
Spiroloculina grateloupi D'Orbigny

"HETEROSTEGINA" ZONE

LIMESTONE

Textulariidae:
Textularia conica D'Orbigny
Textularia gramen D'Orbigny
Bolivina houstonensis Ellisor nov. sp.
Virgulina sp.

Lagenidae:
Cristellaria cf. *rotulata* D'Orbigny
Lagena striata (D'Orbigny) Reuss
Frondicularia sp.

Globigerindae:
Globigerina sacculifera Brady

Globigerina bulloides D'Orbigny
Orbulina universa D'Orbigny

Rotaliidae:
Pulvinulina humblei Ellisor nov. sp.
Pulvinulina texana Ellisor nov. sp.
Siphonina advena Cushman
Discorbis allomorphinoides (Reuss) Cushman
Discorbis orbicularis (Terquem) Berthelin
Spirillina sp.
Planorbulina acervalis Brady
Asterigerina sp.
Gypsina cf. *globulus* (Reuss) Brady

Nummulitidae:
Amphistegina lessonii D'Orbigny
Amphistegina lessonii var. *texana* Ellisor nov. var.
Heterostegina antillea Cushman
Nonionina scapha (Fichtel and Moll) Parker and Jones
Nonionina umbilicatula (Montagu) Brady, Parker and Jones
Lypidocyclina sp.
Polystomella striatopunctata Parker and Jones
Polystomella cf. *macella* (Fichtel and Moll) Brady
Polystomella sagra D'Orbigny
Heterosteginoides sp.

"Marginulina" Zone

Textulariidae:
Bigenerina nodosaria D'Orbigny
Virgulina cf. *schreibersiana* Czjzek
Textularia agglutinans D'Orbigny
Bulimina ovata D'Orbigny
Bolivina houstonensis Ellisor nov. sp.

Lagenidae:
Marginulina philippinensis Cushman
Nodosaria communis D'Orbigny
Nodosaria vertebralis (Batsch) Brady
Cristellaria rotulata (Lamarck) D'Orbigny
Cristellaria cultrata (Montfort) Parker and Jones

Lagenidae:
Cristellaria vaughanii Cushman
Siphogeneriana raphanus var. *texana* Ellisor nov. var.
Uvigerina pygmaea D'Orbigny
Uvigerina byramensis Cushman
Uvigerina aculeata D'Orbigny
Uvigerina tennuistriata Reuss

Globigerinidae:
- *Globigerina bulloides* D'Orbigny
- *Globigerina sacculifera* Brady

Rotaliidae:
- *Pulvinulina humblei* Ellisor nov. sp.
- *Pulvinulina texana* Ellisor nov. sp.
- *Anomalina mississippiensis* Cushman
- *Siphonina advena* Cushman
- *Siphonina texana* Ellisor nov. sp.
- *Siphonina reticulata* (Czjzek) Brown
- *Truncatulina texana* Ellisor nov. sp.

Nummulitidae:
- *Amphistegina lessonii* D'Orbigny
- *Nonionina scapha* (Fichtel and Moll) Parker and Jones

Miliolidae:
- *Quinqueloculina bicornis* Walker and Jacob
- *Spiroloculina tenuiseptata* Brady

Lituolidae:
- *Ammobaculites agglutinans* D'Orbigny

DETAILED SECTIONS

The detailed sections will show the geographic extent of these zones of the Oligocene and also the change in lithology. Possibly future research will reveal sufficient evidence to subdivide these zones into horizons which are constant within a limited area or field, if not over a wider geographic area.

MONTGOMERY COUNTY, TEXAS

Near Willis, in Montgomery County, the Shawver well at a depth of 2,900 feet penetrated 1,000 feet of olive-green and greenish-gray, non-calcareous, shaly and sandy clays, and gray, non-calcareous, clayey sand with an occasional layer of calcareous clayey sand. Lime nodules are present in the clays. The sands range from fairly coarse to fine in texture. The coarse grains are rounded and highly polished. Considerable black jasper and chert are noted in the sands. Occasional layers of volcanic ash are present. The lithology of these sediments resembles the outcropping Catahoula sands and clays, and for that reason is correlated with them. Lack of funds prevented deepening the well and finding out whether or not marine Oligocene is present as far inland as this location.

HUMBLE FIELD, HARRIS COUNTY, TEXAS

On the Humble dome, south of the Shawver well, the Upper Oligocene consists of about 200 feet of light-green, non-calcareous, sandy clay carrying lime nodules and containing some fuller's earth. Light-gray, friable, non-calcareous,

fine-textured sandstone is also present. Here the Middle Oligocene is found at a depth of 3,100 feet, more or less, depending on the location of the wells. The *Discorbis* zone of the Middle Oligocene is usually 100 feet in thickness and consists of greenish-gray, slightly calcareous clay, and light-gray, very fine-grained, calcareous sandstone. The *Heterostegina* zone is very thin and consists of about 100 feet of greenish-gray, calcareous, shaly clay, sandy clay, and light-gray, calcareous, fine-grained sandstone. Below the *Heterostegina* zone and resting directly on the Jackson is a series of light-green, non-calcareous clays carrying lime nodules; light-green, non-calcareous shaly clay; and greenish-gray, calcareous sandstone. There is a thickness of from 400 to 700 feet of these clays. No fossils are present. Because of the character of the lithology and the stratigraphic position, we correlate these beds with the *Marginulina* zone of the Middle Oligocene.

HULL FIELD, LIBERTY COUNTY, TEXAS

At Hull the Oligocene section is similar to that found at Humble. The Upper Oligocene consists of medium-gray, calcareous, sandy clay and greenish-gray, calcareous clay carrying lumps of chalky lime. On different parts of the dome this varies in thickness from 100 to 200 feet. The *Discorbis* zone of the Middle Oligocene consists of dark-gray, shaly clay; dark-gray, calcareous, sandy clay; and light-gray, calcareous, clayey sand, usually 150 feet thick. The lithology of the *Heterostegina* zone includes dark-gray and bluish-gray, calcareous, sandy clay; dark-gray, shaly clay; medium-gray, non-calcareous, sandy clay; and gray, clayey sands. The sand grains range from fairly coarse to fine, angular, subangular, and rounded. Fragments of black jasper characterize the sands. This zone is usually about 100 feet in thickness. Below is a non-fossiliferous zone of non-calcareous, greenish-gray, sandy clays; light-bluish-gray, non-calcareous, clayey sands; and light-gray, slightly calcareous, sandy clays and clayey sands. Gypsum is present, also an occasional bed of volcanic glass. The sands consist of transparent and translucent quartz, rose quartz, prase quartz, and black jasper. The grains vary in size from fairly coarse to fine, angular, subangular, and rounded grains. This zone is 300 feet or more in thickness. As no Foraminifera are present, the exact age cannot be determined. Because of its stratigraphic position we correlate these beds with the *Marginulina* zone the Middle Oligocene.

The character of the lithology of this third zone of the Middle Oligocene, in the area including the fields of Batson, Davis Hill, Hull, and Humble, is very similar to that of the Frio clays as found in wells in Austin, Lavaca, and Duval counties. Both the Frio clays and these clays of the third zone of the Middle Oligocene rest on the same Jackson formation. The stratigraphic position and the similarity of lithologic character strongly suggest the possibility of correlating the Fior with this third non-fossiliferous zone of the Middle Oligocene. As the exact age of the Frio is not yet established, possibly in the future more data will be available so that this zone can be traced westward into the Frio. thereby proving the Frio to be Oligocene in age.

BATSON FIELD, HARDIN COUNTY, TEXAS

At Batson, Hardin County, the Oligocene is similar to that found at Humble and Hull. The Upper Oligocene, or non-fossiliferous zone, consists of about 200 feet of gray, calcareous, clayey sand, with occasional beds of green non-calcareous, shaly clay. Of the fossiliferous Middle Oligocene section, the *Discorbis* and *Heterostegina* zones are present. The third zone is non-fossiliferous. The *Discorbis* zone, 100 feet in thickness, includes gray, calcareous, clayey sands, with occasional beds of dark-green, non-calcareous, shaly clay. The *Heterostegina* zone, less than 100 feet thick, has the same type of lithology, mostly gray, calcareous, clayey sands with dark-green, non-calcareous, shaly clay. Below these beds are dark-green, non-calcareous, shaly clays and olive-green, non-calcareous, shaly clays carrying lime nodules. This series of non-marine clays is 400 feet or more in thickness.

FAIRBANKS, HARRIS COUNTY, TEXAS

In the section at Fairbanks, Harris County, southwest of the area including Humble, Hull, Batson, and Davis Hill, the characteristic Upper Oligocene lithology, yellowish-green, non-calcareous clay with lime nodules; light-greenish-gray, non-calcareous, shaly clay; and light-gray, non-calcareous, sandstone is found from 3,850 through 4,440 feet, the bottom of the hole.

PIERCE JUNCTION, HARRIS COUNTY, TEXAS

South of Fairbanks is the Pierce Junction field. On this dome very few wells have penetrated the Oligocene. The Upper Oligocene varies from 100 to 200 feet of yellowish-green, calcareous, unctuous clay containing lime nodules; light-gray, clayey sand; and sandy clay and sandstone. The sand grains of quartz vary in size from rather coarse to fine. A small proportion of the sand consists of black jasper, rose quartz, smoky quartz, and prase quartz. Of the Middle Oligocene, the *Discorbis* and *Heterostegina* zones are penetrated. The lithology consists of dark-gray, calcareous, sticky clay; light-gray, bluish-gray, and green, sandy, calcareous clay; and light-gray sandstone with calcareous cement. The thickness of the Middle Oligocene penetrated varies from 200 to 450 feet.

GOOSE CREEK, HARRIS COUNTY, TEXAS

At Goose Creek the section shows below the known Miocene and above the known Middle Oligocene, a lithologic unit or zone of non-fossiliferous, medium-gray, calcareous, sandy clays grading into clayey sands. The sands vary from medium-size to fairly coarse, and are composed of transparent quartz and a small percentage of black jasper.

On a paleontologic basis the Middle Oligocene can be divided into the three zones previously described, *Discorbis* zone, *Heterostegina* zone, and *Marginulina* zone. Lithologically, no divisions into characteristic units can be made. A bluish-gray, calcareous, shaly clay is a rather distinctive lithologic feature of the Oligocene in this section. The lithology also includes medium-gray, dark-

gray, calcareous, sandy clays with varying percentages of sand. The sands vary from very fine, angular grains, to rather coarse, subangular grains. Lime nodules and streaks with white chalky lime present. Occasionally greenish-gray, calcareous, and non-calcareous clays are noted. In the second and third zones are layers of calcareous and non-calcareous sandstones, and sands varying in texture from fairly coarse to medium and fine. Glauconite is noted in these sandstones and clays. The Upper Oligocene is usually 200 feet in thickness; the *Discorbis* zone ranges from 100 to 350 feet; the *Heterostegina* zone from 200 to 500 feet; and the *Marginulina* zone averages 300 feet.

WEST COLUMBIA, BRAZORIA COUNTY, TEXAS

Southwest of the area described are the West Columbia and Damon Mound fields. Here a different character of Oligocene lithology is found

For West Columbia the Humble Oil and Refining Company's well, No. 1, Lovejoy, is given as a representative section of the formations. Below 2,930 feet of Pliocene and Miocene clays and sands, there are 227 feet of non-fossiliferous, greenish-gray, calcareous, shaly clays with very fine sand, light-brownish-gray, calcareous, clayey sand and sandstone. The sands range in texture from coarse to fine grains, and consist of transparent quartz, smoky quartz, and jasper. This zone we correlate with the Catahoula because of its stratigraphic position. Below this non-fossiliferous zone is found the *Discorbis* zone of the Middle Oligocene. The lithology of this zone includes 100 feet of fossiliferous, light-gray, and light-greenish gray, shaly clay containing very fine, angular sand grains and lime nodules. The *Heterostegina* zone consists of 225 feet of limestone which varies from a cryptocrystalline to a porous, coarsely crystalline texture. Portions of this limestone are chalky, and lenses or breaks of green clay are present. Parts of the limestone are made up almost entirely of *Heterostegina antillea* and *Amphistegina lessonii*, other parts being almost devoid of fossils. The chalky phase has an abundance of species. The association of Foraminifera found in the shale breaks is different from that in the limestone. The fauna of the limestone includes also Bryozoa, corals, and ostracods which do not occur in the shale.

Below the *Heterostegina* zone is a light-greenish-gray, calcareous, sandy clay and a bluish-gray, calcareous, shaly clay. In these clays is found the association of Foraminifera characteristic of the *Marginulina* zone. This zone is about 100 feet in thickness.

DAMON MOUND, BRAZORIA COUNTY, TEXAS

Damon Mound Field is like West Columbia in the sequence of formations and character of lithology. The characteristic lithologic feature is the limestone of the *Heterostegina* zone. On different parts of the dome this limestone ranges from 100 to 300 feet in thickness, the average being 175 feet. The Humble Oil and Refining Company's No. 2 Gallagher represents a normal section. The base of the Miocene is here at 2,755 feet. The non-fossiliferous zone of gray, calcareous sands and clays is 110 feet thick. Below this zone is the *Discorbis*

zone, which consists of 80 feet of dark-gray, calcareous clay and fine-grained, clayey sand.

The *Heterostegina* zone includes 113 feet of limestone varying from a crypto-crystalline texture to one which is coarsely crystalline. It is the same type of limestone as found at West Columbia and carries an abundant fauna. Below this zone is the *Marginulina* zone with 90 feet of fossiliferous, dark-gray sandy clay and 30 feet of sand and sandstone.

STRATTON RIDGE, BRAZORIA COUNTY, TEXAS

At Stratton Ridge the Oligocene zones are not sharply differentiated. The lithology consists mainly of sands and sandy clays with occasional layers of dark-greenish-gray, calcareous, shaly clays. The *Discorbis* zone consists of about 100 feet of light-gray, fine-grained sandstone and clayey sands, and dark-gray, shaly clay. The *Heterostegina* zone is a thin zone, about 100 feet, consisting of sands and sandy clays carrying an association of Foraminifera somewhat different from the clays and limestones. Below these sands carrying a more or less abundant fauna is a zone of blue-gray, highly calcareous, sticky clay carrying oyster fragments and *Rotalia beccarii*, with an occasional return of the more abundant fauna. The lithologic and the paleontologic character indicates shallow water and shore conditions with a few incursions of the sea.

MISCELLANEOUS

In other fields the information on the Oligocene is very meager, for away from the domes very few of the wildcat wells have gone deep enough to penetrate the Oligocene. In Terry Field, in Orange County, only one well has penetrated the Oligocene. From 5,408 to 5,477 feet a few poorly preserved Oligocene Foraminifera were found in brown clays and gray, clayey sand. At Spindletop, in Jefferson County, the Rycade Oil Company's No. 2 McFadden encountered the Middle Oligocene clays at 4,508 feet. In a wildcat well $2\frac{1}{2}$ miles south of North Dayton field, in Liberty County, the Middle Oligocene clays were found at a depth of 4,140 feet. Near Cross Timbers, in Harris County, at 3,895 feet, were found dark-gray, shaly clays containing Middle Oligocene Foraminifera. In Victoria County, near Victoria, a wildcat well, the Weaver No. 1 of the Guadalupe Valley Oil Company, found the Middle Oligocene at 4,000 feet.

LOUISIANA

For Louisiana our data on the Oligocene are few. In Iberia Parish one well had 520 feet of fossiliferous, calcareous, sandy clays and calcareous, clayey sands varying from light to dark gray in color. In Vinton, Calcasieu Parish, the Oligocene was penetrated by one well which had 70 feet of greenish-gray, non-calcareous, shaly clay containing typical Oligocene Foraminifera. On the Hackberry dome, Cameron Parish, the Rycade Oil Company drilled a well which penetrated the Oligocene at 3,547 feet. Here an abundant Foraminifera fauna was present in a gray calcareous sand. Fifty feet below was found a

green, calcareous, sandy clay carrying numerous specimens of *Rotalia Beccarii* and ostracods. Between 3,592 and 3,833 feet only four samples were taken and no fossils were found in them. The rocks consisted of gray calcareous and non-calcareous sandy clays with varying percentages of sands.

SUMMARY

In the detailed sections which have just been given, the typical lithologic and paleontologic characters of the subsurface Oligocene formations from the outcrop to the coast are described. We find that both the upper non-fossiliferous Oligocene or Catahoula and the fossiliferous Middle Oligocene are present. The Middle Oligocene is divided into three zones which are correlated in the different fields on the basis of micro-paleontology. The lithology of the Middle Oligocene varies from field to field, and with the variation in the lithology, the associations of the Foraminifera vary somewhat.

The Middle Oligocene has proved to be productive on eight of the salt domes of Texas. Goose Creek leads in the production of oil in the Oligocene. Here all three zones are producing. At Damon Mound there is also some production in all three zones. At Hull, the *Discorbis* zone and the *Heterostegina* zone are productive. At Humble, from the *Discorbis* zone and possibly the *Marginulina* zone, producing wells were made. The *Heterostegina* zone is the Oligocene horizon of production for West Columbia, Barbers Hill, Sour Lake, Pierce Junction, and Stratton Ridge.

III. JACKSON AND UPPER CLAIBORNE

GENERAL DISCUSSION

The Jackson formation is the most highly fossiliferous stratigraphic division encountered in the coastal domes of Texas, containing a beautifully preserved, prolific marine fauna which is composed of several distinct members and contains several hundred species of Foraminifera.

During the early days of subsurface investigations in this region when not so much was known about the arrangement of formations in the coastal domes, a portion of this formation was included in the

Oligocene. Later studies of samples from known outcrops of Jackson in Texas, Mississippi, and Alabama have made possible the determination of its true age and stratigraphic relations. Likewise, beds referred to as Bissonett Jackson, or Old Jackson, in early reports are now placed in the Upper Claiborne.

The Jackson, as encountered in wells in the coastal dome area of southeast Texas, is composed of gray to black, and some brown and green, finely sandy shales, with streaks of gray, very fine-grained, friable sandstones. Most of this material is non-calcareous.

In southwest Texas the section is much sandier. In coastal wells of this area, Foraminifera identical with forms found in outcrop samples farther inland have been noted. This fauna grades into the more prolific faunas of lower beds, and the section shows by its uniform character, especially the absence of sharp faunal and lithologic breaks, the relationship of beds which do not outcrop to the higher, outcropping beds. Thus it was found that the lower part of the Jackson section, as developed in coastal wells in southwest Texas, is overlapped at the surface farther inland by the upper part. Consequently, the formation as encountered in wells is much thicker than would be expected when one considers the proximity of these wells to the outcrop of the formation.

In the area above mentioned, the exposed Jackson is composed to a large extent of indurated, fairly coarse-grained sandstones with some loosely consolidated sands and clays. The clays contain the Foraminifera when these are present at all. Macroscopic fossils are frequently present, mostly in sands. Most of these forms are bivalves which often belong to species having extended ranges in the Eocene. The preservation of the forms is usually very poor, so as to make specific determination difficult. Coastward, where buried, the Jackson sandstones are finer grained and more or less unconsolidated.

What has been said about the relation of the outcropping Jackson to the formation as developed in wells in southwest Texas applies likewise to southeast and east Texas. In the outcropping beds in the extreme eastern part of the state is found a beautifully preserved, marine foraminiferal fauna which is more varied in species than in southwest Texas and can be subdivided into faunal zones. The same grouping has been found, with slight variations, not only in

wells of the dome area of southeast Texas, but in places all the way to the Rio Grande. As in southwest Texas, older beds referred to the Jackson occur in coastal wells of southeast Texas than are found in the outcropping section farther inland.

Originally, the true age and stratigraphic position of the marine Jackson in east Texas was determined on the basis of macroscopic fossils. These latter forms, however, were found to be very scarce in wells of the coastal domes and, when present at all, often consisted of new species or immature and fragmentary specimens. They could not be used satisfactorily for identifying and correlating deposits of Jackson age in the salt dome oil fields of the Texas Gulf Coast.

Later, samples were collected from the outcropping beds of the formation and examined for Foraminifera. The result was very gratifying. A well-preserved and distinctive fauna was obtained, the true age of which was known, and, as already stated, this fauna can be traced as far south as the Rio Grande. With good sets of well samples, it soon became a relatively simple matter to identify members of the Jackson formation in the Gulf Coast region. Several expeditions were sent by the Southern Pacific Company to Mississippi and Alabama to collect outcrop material from this and other formations at type localities and historical exposures in these states. The foraminiferal faunas obtained in this manner have been of considerable aid in solving some of our problems. Naturally, there are differences in the assemblage of forms in faunas from Texas when compared with those in these states to the east, but we find the same relationships between faunas in both places.

Foraminifera-bearing deposits of Jackson age have been found at the surface in Angelina, San Augustine, and Sabine counties in east Texas, and in Atascosa, Live Oak, Gonzales, and McMullen counties in south Texas. In the following domes, members of the formation have been encountered: Hull, Sour Lake, Saratoga, Humble, Hockley, Blue Ridge, Damon Mound, West Columbia, Hoskins Mound, Markham, Brenham, Piedras Pintas, and Palangana. Offdome wells in Austin, Live Oak, Goliad, and Starr counties have yielded good sections.

On the basis of faunule groupings the Jackson of Texas has been

divided into the following members, in order downward: Zone A—*Textularia hockleyensis;* zone B—*Textularia dibollensis;* and zone C—*Bulimina*. Besides these fossil zones, the formation contains unfossiliferous beds overlying the *T. hockleyensis* zone at the outcrop in east Texas, and similar beds were found in this position in several coastal wells.

The Upper Jackson at the outcrop in east Texas is composed largely of sands and has not yielded any Foraminifera so far. In the Middle Jackson, as developed in this region, is found a well-developed microscopic fauna consisting of two distinct members, the *Textularia hockleyensis* zone in the upper portion and the *Textularia dibollensis* zone in the lower portion. The Lower Jackson, again, is highly sandy and largely unfossiliferous macroscopically. Until now no Foraminifera have been found in this member at surface outcrops.

FAUNAL ZONES

As has been noted, the upper portion of the Middle Jackson at the outcrop in east Texas is characterized by the *Textularia hockleyensis* fauna. The species present are microscopically fairly small, and the following are the more common forms: *Textularia hockleyensis* n.sp.ms., *T. jacksonensis* n.sp.ms., *Nonionina umbilicatula* Mont. var., and species of *Anomalina*, *Cristellaria*, and *Uvigerina*. The fauna is fairly sparse both in number of species and in specimens.

The *Textularia dibollensis* fauna is similar to that found in the beds above but is distinctive enough to form a separate group. The common fossils in this fauna are *Textularia dibollensis* n.sp.ms., *T. jacksonensis* n.sp.ms., *Nodosaria laevigata* d'Orb., *Pulvinulina jacksonensis* n.sp.ms., *Nonionina umbilicatula* Mont. var., *Cristellaria italica* Defr., and several species of *Quinqueloculina*.

In the coastal fields the *Bulimina* zone comprises several faunules which are found between the *T. dibollensis* fauna and deposits of Upper Claiborne age. The relation between these faunules has not yet been determined, since corresponding fossiliferous beds are absent at the Jackson outcrop farther inland, and different faunules of this zone, when present in domal wells, are usually found immediately underlying Oligocene or even younger strata. That is, the upper portion of the Jackson and some younger deposits are prac-

tically always found to be missing in wells of the salt-dome oil fields where the *Bulimina* zone of the Jackson has been encountered.

Zones A and B are very closely related faunally, but there is a decided paleontological break between these two upper zones and zone C. In the latter zone *Textularia hockleyensis* n.sp.ms., *T. dibollensis* n.sp.ms., *T. jacksonensis* n.sp.ms., and other forms that are characteristic of the upper faunas are absent, and many species that do not occur in zones A and B are present.

A Foraminifera-bearing sample was collected along the road between McVay and Winn, Alabama, by Mrs. E. R. Applin, of the Southern Pacific Company. The sample was obtained from the top of a hill, is stratigraphically from below the St. Stephens Limestone and from above Upper Claiborne deposits which outcrop at the foot of the hill. The horizon of this sample was determined as basal Jackson. The fauna consists of specimens of *Pulvinulina jacksonensis* n.sp.ms., *Bulimina* sp. A, many specimens of *Uvigerina*, and a few other forms. This aggregation bears a close resemblance to faunules of the *Bulimina* zone.

Upper Claiborne deposits have been encountered in three coastal domes: Hull, Humble, and Piedras Pintas. The faunas from the three localities are strikingly uniform, consisting in each case of a large number of well-developed specimens, mainly of *Pulvinulina claibornensis* n.sp.ms., *Rotalia naticoidea* n.sp.ms., *R. soldani* d'Orb., and *Nodosaria mexicana* Cushm.ms.

A study of Upper Claiborne and Jackson foraminiferal sections from outcrops in Alabama shows a marked resemblance between the faunas of these two formations. One phase of the Upper Claiborne in this region is very similar to the Upper Claiborne of Texas, containing an abundance of well-developed specimens of *Pulvinulina claibornensis* n.sp.ms., *Rotalia naticoidea* n.sp.ms., among other forms.

In Texas, likewise, the Upper Claiborne fauna bears a close resemblance to that of the Jackson, very small species, especially, being common to the two formations. *Nodosaria mexicana* Cushm. ms. reported from the Jackson in Mexico is one of the persistent species in the Upper Claiborne fauna. Specimens of *Textularia hockleyensis* n.sp.ms. and *T. dibollensis* n.sp.ms. are not rare in Upper Claiborne samples from Humble. On the other hand, *Pulvi-*

nulina claibornensis n.sp.ms., and *Rotalia naticoidea* n.sp.ms., which are so characteristic of the Lower Claiborne of Alabama, Mississippi, Louisiana, and Texas and do not range into the Jackson in these states, so far as has been noted, are very common fossils in the Upper Claiborne of Texas.

HULL

In the Hull field, many wells have been drilled into the different zones of the Jackson formation and into deposits of Upper Claiborne age. More samples have been examined from the *Bulimina* zone and the Upper Claiborne than from the upper zones of the Jackson.

The *Textularia hockleyensis* fauna as developed here differs from the corresponding fauna at the outcrop in being more prolific, and consisting of larger specimens. The fauna was found in few wells, and the maximum thickness of deposits in any one well in which it occurred was only 150* feet.[1] The upper portion of the zone is missing in these wells, for the fauna as developed here is similar to the lower portion of the *T. hockleyensis* fauna as developed at Humble. Also, in other fields this zone is much thicker. The sediments in this zone consist of greenish-gray, dark-greenish-gray and black, finely laminated and fine-textured shales containing a small quantity of very fine, gray, worn, and polished sand and some glauconite. Streaks of sand and some finely crystalline, white limestone are present in this section.

Immediately underlying the *T. hockleyensis* zone in the well referred to are 150 feet of dark-grayish-brown, very fine-textured, slightly calcareous, and sandy shales and streaks of sand. These shales represent the *T. dibollensis* zone. There is no sharp paleontological break between the two zones, which are both more prolific here than in any other coastal field.

In this same well there is an abrupt change in the fauna between the *T. dibollensis* zone and the sediments below. The lower 40* feet of the well consist of greenish-gray and light-greenish-gray, calcareous, and finely sandy shales and contain the Robinson fauna of the *Bulimina* zone. As far as is known, this fauna is the highest member of zone C. It has been named the Robinson fauna on account of having first been obtained from a well on the Texas Company's Robinson lease at Blue Ridge. It is characterized by the large size of its Foraminifera, the abundance of specimens belonging to certain species and the relatively small number of species. In this well the more common fossils are *Bulimina* sp. A, *Globigerina* cf *inflata* d'Orb. (large variety), large, rimless specimens of *Cristellaria*, and several species of *Uvigerina*.

In another well at Hull, 450* feet of grayish-brown and medium- to dark-

[1] An asterisk after figures denoting thickness of deposits of Jackson and Upper Claiborne age indicates that the thickness does not represent a complete section. When a zone has been drilled through completely, the asterisk is omitted after figures representing thickness.

gray, calcareous, and finely sandy shales containing the Robinson fauna were found underlying 30* feet of shales belonging to the *T. hockleyensis* zone. Unlike zones A and B, where there are found variations in the association of species in different parts of the sections, the Robinson fauna does not show any appreciable change throughout its extent in this well.

The Upper Claiborne consists of medium-gray, dark-gray, and brownish-gray, calcareous, and non-calcareous shales, some being very sandy. The thickest section of this formation observed so far in this field is 450* feet. The more prominent Foraminifera are *Nodosaria mexicana* Cushm. ms., *Pulvinulina clairbornensis* n.sp.ms. *Rotalia naticoidea* n.sp.ms., *Rotalia soldani* d'Orb.

SOUR LAKE

Two wells in this field have shown the *Textularia dibollensis* zone underlying strata of Oligocene age. The fauna is very similar to the *T. dibollensis* fauna as developed at Hull, and is found in 100* feet of dark, calcareous, sandy shales.

Underneath the foregoing zone in one of the wells there are present 100* feet of light- to dark-gray, calcareous to non-calcareous, sandy shales with streaks of sand. These contain the Robinson fauna of the *Bulimina* zone, developed as at Hull.

SARATOGA

In this field, samples representing the lower part of the *T. hockleyensis* zone have been obtained from just above the cap rock in two wells. The fauna is similar to that at Hull.

HUMBLE

At Humble the *Textularia hockleyensis* zone is represented by 700 feet of gray and dark-gray, sticky, calcareous, and non-calcareous shales with a few streaks of impure, soft, fine-grained sandstone and a small quantity of lignite. In this section, the upper 300 feet are sparsely fossiliferous, while the lower 400 feet contain a more abundant fauna similar to that found in the *T. hockleyensis* zone at Hull. However, the Humble fauna is not so prolific as that as Hull but shows a greater variety of Foraminifera than the outcrop section.

In this field 350* feet of gray, calcareous, and dark-gray, non-calcareous, fine-textured shales containing the *T. dibollensis* fauna have been noted. As at Hull, there is no sharp faunal break between zones A and B.

No faunas belonging to the *Bulimina* zone have been found in this field as yet.

Upper Claiborne deposits have been encountered in a number of wells in different parts of the Humble field. They consist of brown, gray, and black, non-calcareous, or only slightly calcareous shales with some soft, impure sandstones. A maximum thickness of 200* feet has been noted so far. The foraminiferal fauna bears a striking resemblance to that found in this formation at Hull. Forms present at Humble, however, include specimens of *Textularia hockleyensis* n.sp.ms., and *T. dibollensis* n.sp.ms., Foraminifera that are characteristic of the upper zones of the Jackson.

HOCKLEY

The Jackson beds encountered at Hockley so far belong to the *T. hockleyensis* zone. They consist of dark-gray, non-calcareous shales with some hard and soft impure sandstones, 400* feet of these sediments having been observed. The fauna is of a simple type, having *T. hockleyensis* as its most prominent fossil. As a Humble, the upper portion of the section is sparsely fossiliferous.

BLUE RIDGE

Gray and dark-gray, calcareous shales with some bluish limestones constitute the Jackson beds found in this field. In wells where this formation has been encountered, the *Bulimina* zone underlies deposits of Oligocene age, the two higher fossiliferous zones of the Jackson being missing. Only the Robinson fauna of the *Bulimina* zone has been found. The Foraminifera aggregation is similar to that occurring at Hull and, as in that field, there is practically no change in the association of species from the top to the bottom of the 300* feet of sediments containing the fauna.

DAMON MOUND

Several faunas belonging to the *Bulimina* zone have been obtained from wells in the Damon Mound field. From only one well were Foraminifera belonging to the *T. hockleyensis* zone obtained. This fauna has some of the smaller species common with fields to the northeast but, on the whole, resembles the *T. hockleyensis* zone of south Texas, which has quite a different aspect from the fauna as developed in east and southeast Texas. Deposits containing this fauna consist of light-bluish-gray, non-calcareous, sandy clay and some light-gray, fairly hard sandstone.

Three different faunas belonging to the *Bulimina* zone have been recognized in this field. Two of them are characterized by species of *Bulimina*, and the third one occurs in heaving shale. The first two faunas consist mostly of larger specimens of Foraminifera, while the heaving shale fauna is made up of many very small, beautifully preserved forms. *Amphistegina lessonii* d'Orb., a species which is not rare in the Oligocene, is found occasionally in the heaving shale of this field. This is the only occurrence of this species in the Jackson noted.

The deposit in which the *Bulimina* faunas are found consist of gray, very dark gray and brownish, non-calcareous, and calcareous shales.

WEST COLUMBIA

More well samples have been examined from West Columbia than from any other field, but the *T. hockleyensis* zone has not appeared in any of the sections. The *T. dibollensis* fauna has been found in only one well, which is rather far out from the dome. *T. dibollensis* is one of the most common species present, and fragments of *Heterostegina* sp. were noted in three samples in the upper 500 feet of the zone. No well-preserved specimens of this fossil were found, and therefore the species could not be identified. This is the only occur-

rence of *Heterostegina* observed in the Jackson of the Texas Gulf Coast. In this well the *T. dibollensis* zone is 800 feet thick and consists of light-gray to dark-gray, calcareous, and sandy shales. The fauna is sparse and quite different from the aggregation of fossils in this zone found in fields to the northeast. However, the fauna can be recognized readily.

Zone C of the Jackson is very similar at Damon Mound and West Columbia. In addition to the faunas found at Damon Mound, three different faunas have been obtained from the heaving shale at West Columbia. One of these is like the heaving-shale fauna from the former field. The true relationship of the faunas of this zone has not been determined, since in different parts of the field different ones of them directly underlie deposits of Oligocene age. The sediments containing these fossils consist of gray and dark-gray, calcareous, and non-calcareous sandy shales.

HOSKINS MOUND

At Hoskins Mound the *T. hockleyensis* fauna has been found in 125* feet of greenish-gray, calcareous shales which lie directly above the cap rock. This fauna has a different aspect from the corresponding faunas farther inland.

MARKHAM

In a well at Markham 30* feet of greenish-gray and light-gray, calcareous, and sandy shales and some soft, white limestone were found to contain the Robinson fauna of zone C of the Jackson. The fauna shows the same development as at Blue Ridge, consisting of large specimens belonging to relatively few species.

BRENHAM DOME AND AUSTIN COUNTY

As at Hockley, the only fossiliferous phase of the Jackson seen at the Brenham dome so far is the *Textularia hockleyensis* zone. Here 750* feet of this zone have been found, consisting of gray to black, non-calcareous, very sandy shales interbedded with gray, fine-grained, friable, impure sandstones. Considerable lignite is present. Foraminifera are unusually scarce, a few having been found occasionally in widely separated samples. This is the most sparsely fossiliferous section of the *T. hockleyensis* zone encountered so far.

An offdome well in Austin County has furnished an excellent section of zones A and B of the Jackson. This section shows a transition between the faunas of east Texas and the corresponding south Texas zones. There are present in this well 750 feet of the *T. hockleyensis* zone consisting of gray to black and green, non-calcareous, and sandy shales and some very fine-grained, gray, impure sandstones. Occasional streaks of lignite were noted. The fauna is very sparse, being in this respect like that at Hockley.

The lower 300* feet of the well, the *T. dibollensis* zone, consists of black, carbonaceous, partly non-calcareous and partly calcareous, sandy shales interbedded with sands. The *T. dibollensis* fauna is more prolific than the overlying one and contains a number of species of Foraminifera peculiar to the south Texas section. There is a distinct faunal break between zones A and B. *T. hockleyensis*

is abundant and confined to the upper zone, while the same holds true of *T. dibollensis* and the lower zone. In this region the fauna in the lower zone contains about twice as many species as that in the zone above. An occasional re-worked foraminifer was found in both zones.

LIVE OAK COUNTY

In Live Oak County another good section of the Jackson has been obtained from undisturbed beds, including all of zones A and B. This is a typical south Texas section.

Underneath the Fleming in the area studied lie 600 feet of sediments of Frio age. These deposits consist of light-green, calcareous, pure clay containing beds of volcanic ash. No Foraminifera were noted, except a few re-worked Cretaceous forms.

The upper 400 feet of the Jackson are composed of light-green, calcareous clay similar to the Frio but interbedded with gray sand and volcanic ash. No fossils, except a few re-worked Cretaceous Foraminifera, were seen. Below this unfossiliferous section lies the *T. hockleyensis* zone. It consists largely of sands, and at the outcrop was formerly known as the Fayette formation. This zone is very thick here, consisting of 1,400 feet of soft, impure, non-calcareous sandstones interbedded with gray and greenish-gray, calcareous and non-calcareous shales. The shales become darker toward the bottom of the zone. The sands carry a pelecypod and gastropod fauna consisting of few species but many specimens. Among the Foraminifera *Textularia hockleyensis* n.sp.ms., two small species of *Polystomella* and several small ones of *Nonionina* are prominent. The *Textularia dibollensis* zone consists of dark-grayish-green and light-green, non-calcareous shales interbedded with dark-greenish-gray, very fine-grained, soft sandstones that are finer grained than those in the zone above. A few pelecypods and gastropods and a well-developed foraminiferal fauna is present.

A similar relation exists here between zones A and B as in Austin County. In both places zone A carries such characteristic fossils as *Textularia hockleyensis* n.sp.ms., and species of *Polystomella* and *Nonionina*, while in zone B are found *Textularia dibollensis* n.sp.ms., species of *Nonionina* different from those in zone A and *Nodosaria laevigata* d'Orb. A few scattered re-worked Cretaceous Foraminifera were found in both zone A and zone B.

Underlying the *T. dibollensis* zone were found 100* feet of greenish-gray, non-calcareous shale which contains a Claiborne foraminiferal fauna. Due to the sparseness of the fauna, its position in the Claiborne could not be determined.

GONZALES COUNTY

A surface sample from the southwestern part of Gonzales County was found to contain specimens of mollusks and a well-developed *T. hockleyensis* fauna. The latter is similar to that found in the upper part of zone A in the Live Oak County section. The sample consists of green clay and came from close to the Jackson-Yegua contact.

GOLIAD COUNTY

Information from Goliad County is based on samples representing the lower 700 feet of a deep well. The upper 200* feet of this section consist of very dark gray shales belonging to the *T. hockleyensis* zone. These shales contain only one species, *Textularia hockleyensis*—an unusual situation.

Immediately underneath the foregoing zone lie 500* feet of sediments carrying the *T. dibollensis* fauna. The deposits consist of dark-gray and some light-gray shales. The upper half of this zone contains a fauna similar to the *T. dibollensis* fauna in Live Oak County, while the lower portion contains unusually large specimens of *Textularia dibollensis* and, besides, a more abundant fauna than the upper phase. A similar change in the *T. dibollensis* fauna was noted in Austin County.

PALANGANA

At Palangana, 1,400 feet of sediments belonging to the *T. hockleyensis* zone have been found in one well. These sediments consist of light- to dark-gray and greenish-gray, calcareous, and sandy shales interbedded with some friable sandstones. Brown shales are present occasionally near the bottom. The fauna has the same aspect as the *T. hockleyensis* fauna in Live Oak County.

Underneath zone A were found 600 feet of unfossiliferous sediments, the upper half consisting of light-bluish-gray, calcareous, and sandy shales, and the lower portion of similar gray shales.

The lowermost 100* feet of the well consist of gray, calcareous, and sandy shales containing a *T. dibollensis* fauna like that from Live Oak County.

PIEDRAS PINTAS

In one of the few wells from which samples were examined, a simple *T. hockleyensis* fauna like that from Live Oak County was washed out of dark-gray, calcareous, and sandy shales.

The only fauna older than the foregoing that was obtained from this dome is of Upper Claiborne age. The remarkable feature about this fauna is that it is very much like that at Humble and Hull, the same species being prominent as in the latter two fields.

STARR COUNTY

In the Marland Oil Company's Santo Domingo well in Starr County there was found between the depths of 2,600 and 2,998 feet a well-developed foraminiferal fauna which is foreign to Texas. It has Jackson affinities but cannot be correlated with any one of the Jackson fossiliferous zones which are persistent from the Sabine to the Rio Grande. This portion of the well consists of gray sands and sandy clays.

Surface samples were collected in northeastern Mexico immediately to the east of the Fayette (Jackson) outcrop by Texas Company geologists, and these samples yielded Foraminifera like those from between the depths of 2,600 and 2,998 feet in the Santo Domingo well.

Below this fauna, in the above well, in a sample from 2,998 feet, an association of Foraminifera like that characteristic of the upper part of the *T. hockleyensis* zone as developed in south Texas was found.

The same relation of faunas as in the Santo Domingo well was observed in the Mirando Oil and Gas Company's Kelsey No. 2. Here a sample from 820 feet consisting of light-gray, calcareous, and sandy clay contains a fauna similar to the upper one (2,600–2,998 feet) in the Santo Domingo well. This sample was immediately above 400* feet of gray sands and calcareous and sandy clays containing a typical *T. hockleyensis* fauna of the south Texas type.

LOUISIANA

Practically no Jackson samples have been examined from wells in Louisiana. A wildcat well in La Salle Parish drilled into the *T. dibollensis* zone, the fauna being developed as in the outcrop section in east Texas.

Samples of Jackson age have been obtained occasionally from wells in the Vinton Field, Calcasieu Parish. Due to the scarcity of these samples, the character of the Jackson section in this area has not yet been determined.

A RECONNAISSANCE STUDY OF THE SALADO ARCH, NUEVO LEON, AND TAMAULIPAS, MEXICO[1]

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ABSTRACT

In the part of Northeastern Mexico that borders the Rio Grande are a number of geological structural features which may mark important oil possibilities. The Salado Arch is a prominent anticline with northwesterly axial trend, approximately 100 miles long, in Nuevo Leon and Tamaulipas. Upper Cretaceous rocks are exposed along the crest of the arch and to the west where an east-facing escarpment marks the westward dip of the beds. A few miles east of the axis of the arch and running parallel to it is a very prominent west-facing escarpment, the upper rocks of which are of Eocene age. A measured section of the latter shows a total thickness of 5,422 feet. The anticline plunges southeast and the steeper limb of the fold is on the basinward rather than the mountainward side. Prospects of oil production are favorable on account of the probable occurrence within drilling distance of petroliferous formations equivalent to those of the Tampico embayment.

INTRODUCTION

Unless unforeseen developments occur, the oil fields of Tampico have passed the peak of production. The pools of the Dos Bocas—Alamo district, the once marvelous "Golden Lane" of Mexico, are partially or completely flooded by salt water. The Panuco fields have in the past year experienced a revival in activity furnished by the Cacalilao pool. However, unless new fields are developed, it appears inevitable that Mexico will, in the course of a few years, fall from the position which she now holds as the second greatest producer of petroleum in the world; and it seems likely that the fall in production will be as spasmodic as was the rise.

Coincident with the decline of petroleum productivity in the Huasteca region, there has been a search for potential oil fields outside the Tampico embayment. That part of Northeastern Mexico in Nuevo Leon and Tamaulipas bordering the Rio Grande contains structural features which have aroused general investigation.

Among the prominent structures of this area may be mentioned the Aldamas anticline, deriving its name from the town of Los

[1] Published by permission of the Humble Oil and Refining Co., Houston, Texas.

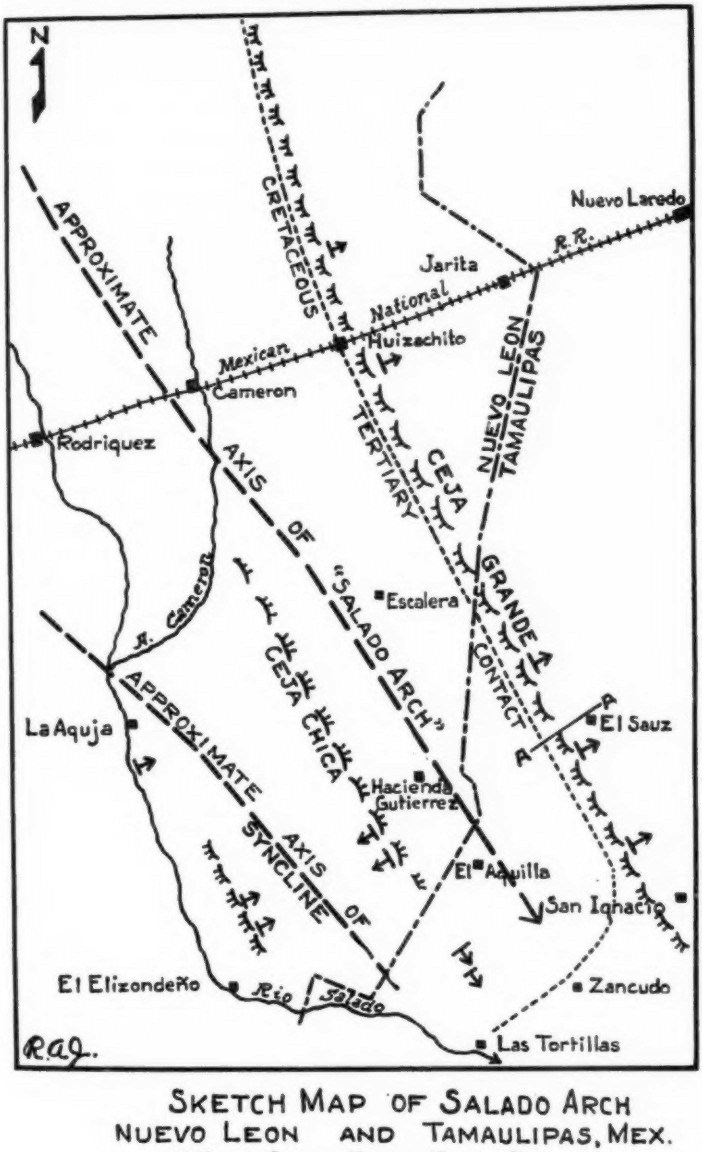
Aldamas, Nuevo Leon. North of the Aldamas fold is the Guerrero anticline, located about 8 miles west of south of Guerrero, Tamaulipas, and approximately 15 miles northeast of Parás, Nuevo Leon. The Guerrero anticline is of the "picture" variety, expressing itself in a narrow, eroded anticlinal valley, bordered by sandstone-capped hills—a delight to the eye of the Gulf Coast geologist who has become accustomed to the vague, uncertain expression of structure which characterizes the soft surface rocks of many producing oil fields. The fold is approximately 8 miles long by 3 miles wide at the place of greatest width. Northwest of the Guerrero anticline are the hills of La Lajilla, east of the Rio Sabinas and near Rancho La Lajilla. The structure here appears to be due principally to faulting. North of La Lajilla and about 10 miles northeast of the village of Las Tortillas, Tamaulipas, on the Rio Salado, are the rather complex structural conditions of the Tanque-Barreta area. No doubt many minor folds exist which detailed examination will reveal.

This brief statement summarizes certain of the main structures of the Rio Grande area in Northeastern Mexico, which may in the future become the site of important oil fields. The present paper is not, however, concerned with them but with the adjacent region to the north, the region which has been termed by the author the "Salado Arch." It is a reconnaissance study[1] of the larger geologic features of the territory roughly defined as follows: the part of Nuevo Leon and Tamaulipas lying between the Rio Grande and the Rio Salado, and extending from Las Tortillas, Tamaulipas, to Laguna de la Leche, at the extreme northern tip of Nuevo Leon. The line of the Mexican National Railway from Nuevo Laredo to Monterey passes through this area.

TOPOGRAPHY

The region of the Salado Arch presents a diversity of topography so mantled by mesquite and chaparral as to appear confusing at first. However, taken as a whole, the topography is distinctive; and may be resolved into clear-cut, definite features.

[1] The field work upon which this paper is based was done by the writer in September and October, 1922, for the Humble Oil and Refining Co., Houston, Texas, in conjunction with Messrs. Paul Applin and Lyman Reed, of the Rio Bravo Oil Co., Houston. The writer examined the area further in April, 1923.



SKETCH MAP OF SALADO ARCH
NUEVO LEON AND TAMAULIPAS, MEX.

FIG. 1

In the eastern part of the area is a prominent line of hills or escarpment, the Ceja Madre, or, as it is more commonly called by the inhabitants, the Ceja Grande. With an abrupt descent on its southwest side, this escarpment is a remarkable physiographic element. It trends N. 40° W. from near San Ignacio, Tamaulipas, to Huizachito, Nuevo Leon, on the Mexican National Railway, where it bends to a slightly more northerly course and continues in a northwesterly direction to Laguna de la Leche, which is at the north end of Nuevo Leon, lying partly in that state and partly in Coahuila. From San Ignacio to Laguna de la Leche is approximately 75 miles. North of Laguna de la Leche and beyond the Arroyo Agua Verde, Coahuila, the hills continue with more northerly trend, but here they are known as the Ceja Macha. South of the railroad between Nuevo Laredo and Monterey is a low range of hills known as the Ceja Chica. This ridge is less marked than the Ceja Grande but roughly parallels it and, like it, also presents an abrupt slope on one side. However, the scarp of the Ceja Chica faces northeast, looking directly into the southwest-facing scarp of the Ceja Grande. Between the Ceja Grande and the Ceja Chica, nowhere more than about 10 miles apart, is an undulating plain, in striking contrast to the rugged bluffs on either side.

North of the railroad the topographic features are less distinct. The Ceja Grande persists, but the Ceja Chica dies out. Near Rodríguez, Nuevo Leon, is a flat plain through which the Rio Salado flows tortuously. Some 30 miles northwest of Rodríguez and just west of the Rio Salado rises the Sierra de San Juan or, as it is also called, de La Laja, a rounded, small, anticlinal mountain range, the type locality of the San Juan limestone.[1] East of the Sierra de San Juan on the other side of the Rio Salado is a low group of gravel-covered hills, the Lomas de San Antonio. In the region between the Ceja Grande and the Rio Salado is an extensive plain, surrounding the Lomas de San Antonio, which is of greater size and even more featureless and monotonous than the plain south of the railway. It is in large measure an old lake bed, remnants of which persist as grass-covered flats or "lagunas," the largest of which is Laguna de la Leche.

[1] E. T. Dumble, "Tertiary Deposits of Northeastern Mexico," *Proc. Cal. Acad. Sci.*, Vol. 5 (1915), p. 173.

West of the general area from Las Tortillas to Laguna de la Leche, a bird's-eye view reveals various ranges of hills and mountains —the Sierra de Vallecillos, the Sierra de la Iguana, the Sierra de Lampazos, the Sierra Azul, and the Mesillas, the Mesa de Cartujanos. Beyond these are the jagged peaks of the Sierra Madre Oriental.

THE CRETACEOUS-EOCENE CONTACT AND THE ESCONDIDO OUTCROP

In Texas the Cretaceous-Midway contact crosses the Rio Grande in Maverick County about $4\frac{1}{2}$ miles above the Webb-Maverick County line. Here at White Bluff the Escondido contact[1] with the characteristic fossiliferous, basal Eocene limestone may be seen. One mile downstream the Midway limestone occurs in the bed of the river opposite the Blessé ranchhouse on the Coahuila side.

Concerning the continuation of the contact in Mexico, Dumble states:

> The contact between the Cretaceous and Eocene in Mexico was first found on the Arroyo Caballero, a small creek which empties into the Rio Grande on the Mexican side some three or four miles north of the Maverick-Webb County line in Texas. From this point the contact runs southwest to the hills north of Azulejo, where it turns and runs a little east of south, crossing the Salado River near Rodríguez, the Sabinas near Piedras Pintas, and the Salinas at Ramones.[2]

Dumble clearly recognized the presence of uppermost Cretaceous or Escondido[3] beds north of the railway between Nuevo Laredo and Monterey, but he apparently did not recognize their presence south of the railroad; and, accordingly, drew the Cretaceous-Tertiary contact as crossing the Rio Salado near Rodriguez, Nuevo Leon. More detailed investigation has revealed the occurrence of extensive deposits of Upper Cretaceous age a short distance north and south of the railway and east of the Rio Salado almost as far as Las Tortillas, Tamaulipas.

There is in this territory between the Ceja Grande and the Rio Salado a series of beds of blue and yellowish shales, intercalated

[1] For discussion of the Escondido-Midway contact on the Rio Grande, with photographs, see L. W. Stephenson, "The Cretaceous-Eocene Contact in the Atlantic and Gulf Coastal Plain," *Prof. Paper 90, U. S. Geol. Survey* (1914), pp. 168–76.

[2] E. T. Dumble, *op. cit.*, pp. 171–72.

[3] *Ibid.*, pp. 169, 173, and 174.

with thin brown sandstones and carrying large yellow-brown calcareous concretions or septaria, often shot through with calcite veins, which furnish in widely scattered places fossils of Upper Cretaceous age.[1]

In the light of this evidence, it appears certain that a belt of sediments of Upper Cretaceous age parallels the Ceja Grande both north and south of the railroad. They are the youngest Cretaceous in the area and have been considered by the author as a continuation of the Escondido beds mapped by Dumble north of the railway line.

Along the Rio Salado south of Rodriguez a series of olive, nodular shales with a considerable number of interbedded thin sandstones crops out, resting on a series of blue-black, nodular shales with a lesser number of interbedded thin sandstones, which are probably of Pappagallos age. The author does not feel justified in the light of his present knowledge in making a definite statement concerning the Escondido-Pappagallos contact, but it appears likely that the contact may approximately follow in this vicinity the Rio Salado.

Dumble[2] states that Wilcox and Carrizo beds occur near the mouth of the Arroyo Reparo a short distance northwest of Rodriguez, thus indicating a Tertiary transgression over the Cretaceous. The writer believes that the beds here exposed are Cretaceous, as evidenced by the lithology and foraminiferal fauna, rather than Tertiary.

The rocks forming the Ceja Grande are undoubtedly Eocene in age. The Cretaceous-Eocene contact should be placed practically at the foot of the Ceja Grande escarpment from Laguna de La Leche, Nuevo Leon, to near Rancho Zancudo, Tamaulipas, about 6 miles northeast of Las Tortillas, thus classifying as Cretaceous a large territory east of the Rio Salado, which has previously been considered to be Eocene.

[1] Upper Cretaceous fossils are found at the following localities: 1 mile north of Rancho El Aguilá between El Sáuz and Las Tortillas, *Gryphea vesicularis* and *Exogyra costata;* about 12 miles west of north of Las Tortillas on trail to Rancho Escalera, many *Gryphea vesicularis;* on a low hill, the Loma del Lobo, about 8 miles southeast of Huizachito, *Gryphea vesicularis;* between Loma del Lobo and Rancho Escalera, *Exogyra costata.* The foregoing localities are all south of the railway, but north of the railway, on a hill about 10 miles northwest of Huizachito, numerous specimens of *Exogyra costata* are again encountered.

[2] *Op. cit.*, p. 174.

SECTION OF EOCENE IN CEJA GRANDE AT RANCHO EL SAUZ, TAMAULIPAS

The Tertiary rocks of the Ceja Grande dip northeast at a steep angle and expose a great thickness of beds. A good section may be measured in the hills of the Ceja Grande near Rancho El Sauz, Tamaulipas (line *A–A*, Fig. 1). In the short distance of approximately $3\frac{1}{2}$ miles there are exposed 5,422 feet of sediments. No attempt has been made at correlation of the series with the various subdivisions of the Eocene, but it will be noted that lithologically the beds are readily divisible into three main parts, in order from top to bottom as follows: (3) 1,453 feet of interbedded shales and greenish sands, in places carrying coal; (2) 1,029 feet of red sandstone; (1) 2,940 feet of intercalated yellow olive, and green shales and brown sandstones with some thin beds of impure, fossiliferous limestone. As will be noted under "Structure," there is a possibility that these thicknesses may be in part due to duplication of beds by faulting. The El Sauz section[1] follows:

TABLE I

	Thickness* Feet
Shale plain	?
Soft brown sandstone, strike N. 60° W., dip 10° NE.	
Interbedded green and brown sandstones and shale; shale predominating in upper part and sandstone in lower part	
Sandstone of considerable thickness; some sandy shale. Strike N. 60° W., dip 10° NE.	
Massive sandstone with associated thinner beds. Forms fourth ridge in Ceja Grande at El Sauz. Cannel coal mined at this horizon at Rancho La Palma, a short distance SE. This cannel coal may perhaps be correlated with that in the mines of Webb Co., Texas, N. of Laredo, which is held to be Cook Mountain or Mount Selman in age	740
Green, yellow, and bluish sands, considerable thickness	
Massive, soft blue sandstone, 4 ft. thick	
A thin, hard, gray limestone, practically a breccia of *Venericardia* shells. Just above Arroyo Sauz	293
Massive yellow and green sandstone in bed of Arroyo Sauz. Medium-grained, micaceous, cross-bedded in places. Strike N. 45° W., dip 20° NE.	118

[1] Measured with plane table.

* The thicknesses in margin of section refer, not to specific beds, but to measurement units, comprising groups of beds. Any data as to specific thickness of a certain single stratum will be found in the lithologic description of the section.

Greenish, thin-bedded sandstone. Below this the green sands disappear	302
Red sandstone. Medium to coarse-grained, thin-bedded, ferruginous	
Red sandstone. Medium-grained, massive, about 10 ft. thick. Weathers into irregular shapes, strongly ripply-marked in places. Forms hogback ridge—the third ridge in Ceja Grande at El Sauz. Strike N. 60° W., dip 20° NE.	587
Massive, red sandstone, also thin strata. Medium- to coarse-grained. In narrow valley.	
Red sandstone. Medium-grained, massive, ripple-marked. Weathers into fantastic forms. Forms second ridge in Ceja grande at El Sauz. Below this the red sands disappear	442
Thin-bedded sandstone, brown and white	
Brown, fine-grained sandstone, about 20 ft. thick. Strike N. 45° W., dip 30° NE.	206
Yellow shale and interbedded soft brown sandstone	
Thin layer of red, ferruginous clay-ball conglomerate, associated with calcareous yellow concretions. Contains small oyster shells. Forty ft. above underlying heavy sandstone	
Massive, soft, fine-grained, micaceous sandstone, 10 ft. thick. Strike N. 60° W., dip 20° NE.	301
Olive shale and interbedded sands	
Soft, micaceous sandstone, rather massive, 15 ft. thick, micaceous	542
Interbedded sandstone and green shale	
Thick-bedded sandstone, about 20–30 ft. thick, brown. Strike N. 70° W., dip 20° NE. Immediately below this sand is a thin, brown, impure limestone, highly fossiliferous, but so indurated that fossils cannot be broken out. Weathered surface shows cross-sections of oysters and gastropods	342
Yellow-green shale and thin sandstones	292
Soft, fine-grained yellow sandstone, with minor amount of shale. Strike N. 75° W., dip 15° NE.	74
Yellow and olive shale	
Thin, dark-brown limestone, very fossiliferous. Lies on yellow, calcareous concretionary layer. Contains many *Venericardia planicosta*, *Turritellas*, corals, oysters	
Green shale	
Sandstones, 3 and 4 ft. thick, and green shale. Strike N. 80° W., dip 20° NE.	
Yellow green shale	
Thin, well-indurated sandstone, with many broken shell fragments	638
Yellow and green sandy shale with a few beds of brown sand	176
Interbedded sandy shale and soft to hard, brown sandstones. Limonite concretions; a few large calcareous concretions. Large amount of sandstone in section. Strike N. 80° W., dip 21° NE.	242

Thin-bedded, slabby sandstone, upper layer ferruginous. Forms first or front ridge of Ceja Grande in El Sauz section. Strike N. 45° W., dip 16° NE.	
Intercalated thin, brown sandstones and blue and yellow sandy shale..	52
Hard, brown sandstone, in places coated with iron oxide	
Gypsiferous, yellow shale. Cast resembling *Cucullea macrodonta* found. Interbedded with thin layers soft, brown sandstone. Strike N. 50° W., dip 16° NE.	
Large, yellow concretions (starting-point of section in plain at foot of Ceja Grande escarpment)	75
Total thickness	5,422

STRUCTURE

There is evidence of the existence of a large anticline in this region, which the author has called the "Salado Arch." The Tertiary sediments of the Ceja Grande hills or escarpment dip northeast from 5° to 30° from the northern limit of the area examined at Laguna de la Leche to near San Ignacio, Tamaulipas. The strike of the beds varies from N. 20° W., to N. 80° W. Approximately 75 miles of strong northeast dip were observed along the Ceja Grande.

A short distance north and northwest of Las Tortillas the general dip changes to southeast, as evidenced by several hogback hills, which have pronounced dips of about 3° in a direction of S. 40° E. Going northwest from these hills, the northeast-facing escarpment of the Ceja Chica south of Hacienda Gutiérrez shows definite dips of from 1° to 3° in a direction from S. 30° W. to S. 45° W. Thus, the dip swings from northeast in the Ceja Grande, near the south end of the area, to southeast in the hills above Las Tortillas to southwest in the Ceja Chica, a condition indicating a plunging anticline.

The topographic features of the opposing scarps of the Ceja Grande, facing southwest, and the Ceja Chica, facing northeast, have been noted. As one drives through the valley between the two ranges of hills this contrast is striking. The topography is in accordance with the anticlinal evidence afforded by the dips, and the logical conclusion is that an anticlinal axis passes between the Ceja Grande and the Ceja Chica. The precise location of this axis can be determined closely only by very careful examination.

West of the Ceja Chica between these hills and the Rio Salado

from Rancho La Aguja on the river to Las Tortillas there are indications of a syncline. The prevailing dips along the river below Rancho La Aguja are to the northeast. North of Rancho Elizondeño is a southwest-facing scarp with northeast dip, in contrast to the southwest dips in the scarp of the Ceja Chica south of Hacienda Gutiérrez.

The Salado Arch is a southeastward plunging anticline, trending northwest and southeast roughly parallel to the anticlinal mountain ranges to the west. It is most clearly defined south of the line of the Mexican National Railway from Nuevo Laredo to Monterey, but is believed also to extend north of the railroad. It differs from many anticlines found on the skirts of mountain ranges in that the limb with the steeper dip is on the basinward instead of the mountainward side of the fold. It is not within the scope of this paper to discuss the orogeny of the fold with relation to the mountain-building of Mexico, nor to enter upon a discussion as to the time at which the anticline was formed, save that the movements, having affected Eocene beds, must have endured into Post-Eocene times, no matter at what period the movement was initiated.

No definite Eocene has been found on the west side of the fold nor do the Cretaceous beds show the areal arrangement that might be expected. Starting at the Ceja Grande a traverse to the west leaves behind the Eocene sediments and passes through the regular sequence of Cretaceous strata, going continually, as regards major subdivisions of the Cretaceous, from younger to older beds. The question immediately arises: Why do Tertiary beds not occur on the west limb of the fold? Why is there an uninterrupted sequence of Cretaceous rocks across the fold? In answer it may be suggested that the anticline is asymmetrical—the dips on the west limb are much gentler than those on the east limb (a contrast of 1° and 3° dips with dips of an average magnitude of 20°). Possibly it has resulted from this that the folding has not been sharp enough to permit erosion to disarrange the stratigraphic sequence of the Cretaceous, i.e., to expose Pappagallos within the Escondido outcrop. With regard to the absence of Tertiary on the west limb, it is possible that the folding began in Cretaceous time and that in Eocene time a low barrier was formed, which prevented later deposition of Eocene on the west side of the fold.

The thickness of the Eocene beds in the Ceja Grande suggests that there may be some duplication of beds through strike faulting, and close examination of the Ceja Grande may reveal considerable faulting. Near Huizachito in the railway cuts there is some minor crumpling, chiefly due to thrust.

On a fold of this size—it extends about 30 miles in a straight line from Las Tortillas to the railroad and probably still farther north of the railway—there are undoubtedly local domes and faulting, which will be found by detailed investigation. These local features should facilitate petroleum accumulation. Additional oil reservoirs are constantly being discovered in comparatively small structures associated with larger regional structures or structural trends, as the pools on the Bend Arch in north-central Texas, the fields at Mexia, Powell, and Luling in central and east-central Texas along the Mexia fault zone, and the fields of Webb and Zapata counties, southwest Texas, along the Reynosa fault zone. The Upper Cretaceous is exposed on the crest of the Salado Arch, and when smaller structural conditions superimposed upon it are located, favorable drilling sites may be selected. Prospects of commercial production are greater on account of the proximity to the surface of the San Juan (San Felipe) and Tamasopa limestones, which have yielded the oil at Tampico. On this account the Salado Arch offers more favorable drilling conditions than other structures in northeastern Mexico along the Rio Grande, where a great thickness of Eocene must be penetrated before the Upper Cretaceous is reached.

Only the drill can reveal whether the Cretaceous limestones will be productive, but the region of the Salado Arch should be given serious consideration in the future exploitation of the possible oil resources of Mexico.

CHAPEÑO SALT DOME, TAMAULIPAS, MEXICO

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ABSTRACT

A sulphur deposit in Tamaulipas is described with discussion of its probable relations to a salt dome.

The title of this brief paper is consequent upon the belief of various oil men and geologists that a sulphur deposit located on the Chapeño ranch in Tamaulipas rather definitely signifies the presence of a salt dome. The deposit might better be described under its local name, "Mina de la Pita," signifying the "Maguey Mine,"[1] but, while not expressing final conviction that the deposit does signify a salt dome, the author believes that the sulphur is rather unexplainable upon any other hypothesis.

The "Mina de la Pita" is located on the Chapeño ranch in the northern district of the state of Tamaulipas, in the municipality of Matamoros, 33 miles by air line from the city of Matamoros, 5 miles south of the ranch "San Bartolo," and $1\frac{1}{2}$ miles east of the ranch "Chaparral." It is 5 miles from the Laguna Madre and 15 miles from the Gulf of Mexico.

The deposit is situated in the Gulf coastal plain, the characteristics of which are exactly those of the Gulf coastal plain throughout southeast Texas. The mine itself is located on a very slight elevation, probably a little more than 10 feet above the surrounding flats, the elevation being so small as to be practically imperceptible without the use of levels. Unfortunately, a topographic map of the area is not available.

Just how long the existence of sulphur at this point has been known cannot be learned. The writer's attention was first called to it in 1918, but previous to that it had undoubtedly been known for a long time.

At the time this prospect was visited in 1919, the so-called mine consisted of two or three pits from 5 to 8 feet deep, located on the highest part of the ground. These pits, after passing through the

[1] The name probably comes from the fact that maguey plants occur in the vicinity of the mine.

surface soil, composed of about 3 feet of dark clay very strongly impregnated with gypsum, native sulphur, and calcite, entered some 6 feet of blue clay, which contains streaks of free sulphur and many crystals of selenite, and, when freshly exposed, gives off considerable quantities of hydrogen sulphide gas. The gypsum and sulphur appear in larger quantities in the surface soil than they do in the underlying blue clays. Their association in the soil is with a loose, white material, which seems to be a surface deposit in the nature of caliche, and which is undoubtedly calcium carbonate and gypsum. This deposit, although mixed with the surface clays, appears very constantly over an area of 2,000 feet square surrounding the mine. Throughout this area it carries large quantities of sulphur, sufficient in the three pits which the author dug or reopened, to give it a yellow color. Many large pieces were taken from the pit, which contained enough sulphur to support a flame. Gypsum crystals appear in this deposit associated with the sulphur. Investigations outside of the 2,000 feet square area around the mine found the calcareous material not altogether missing under the soil, but in no case were sulphur or gypsum crystals found in it outside of the area adjacent to the mine. An area 2,000 feet square, with the mine roughly in the center, was examined by digging shallow holes down through the soil, and over this whole area sulphur and gypsum crystals were encountered.

At a distance of about 1,000 feet from the mine there is a well which was drilled in 1907 or 1908. Very salty water stands to the top of the 6-inch casing at the present time, but there is now no remnant from the cuttings from the well. The writer, at the time of his visit, had a log of this well which indicated that it reached a depth of 620 feet, that at this point considerable gas and some oil were encountered, and the well was abandoned. On account of the absence of reliable information about the well, it is probably better to disregard any of the reports concerning it, but it seems fairly certain that it was drilled with a water-well outfit, and accordingly that it was not drilled very deep.

The hypothesis that "Mina de la Pita" is a salt dome seems to be the only one which accounts for the presence of so much sulphur and hydrogen sulphide gas as appear at this point, since other agencies which might give rise to this deposit of sulphur are, so far as we know, totally unknown in the Gulf Coast of Mexico and Texas.

STRATIGRAPHY OF THE TAMPICO DISTRICT OF MEXICO

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ABSTRACT

Geological research in the Tampico district of Mexico during the last few years has resulted in accumulation of much detailed stratigraphic information, but work has been attended by some confusion. A general description of the rock formations of the district is here presented, the nomenclature and stratigraphic definitions in most common use being outlined. Beds of Lower, and Upper Cretaceous, Eocene, Oligocene, and Miocene age are recognized. The total thickness of these divisions appears to be more than 16,000 feet. The chief oil-producing formation is the Tamasopo limestone of Lower Cretaceous age; important quantities of oil have also been obtained from the upper part of the Tamaulipas formation, Lower Cretaceous, and the lower part of the succeeding San Felipe formation, Upper Cretaceous.

INTRODUCTION

It is intended in this paper to describe the formations in the oil fields of the Tampico district, Mexico, and adjacent territory, for the purpose of establishing formation names, the general use of which will permit a common understanding among workers in the field, and to make a classification which will serve as a basis for further work on the stratigraphy of the region.

The formations with which the geologist has to deal are divided in a manner most convenient both for field correlations and recognition in well cuttings. However, only the broader divisions which are easily distinguished and which have been recognized over wide areas are presented. Although the faunas of the various formations are sufficiently well known to establish the ages of the beds and to distinguish units which can be used safely in the field and in the study of well samples, no attempt is made here to catalogue or describe these faunas. Similarly, no attempt is made to correlate the Tampico section with the Texas section—although this also can be accurately done. The purpose of the paper is rather to describe the Tampico section so that beds in new areas can be referred to it.

The bewildering number of new names for formations, introduced

during the past ten years as new workers have come into the field, has caused some confusion. In this attempt to eliminate the confusion already existing and to prevent further confusion, the writer has chosen the nomenclature in most common use by the geologists now working in the field for generally recognized formations, preferring to use an established name even though its present application differs slightly from its original definition. With the exception of Tamesí and Tempoal, the formation names used originated in unpublished and published reports[1] of G. Jeffries, W. F. Cummins, E. T. Dumble, E. DeGolyer, L. W. Stephenson, and E. L. Ickes.

The geologic section to be discussed is as follows:

Miocene
- Tuxpam formation

Oligocene
- Mesón formation

Eocene
- Alazan shales
- Tantoyuca formation
- Tempoal shales
- Chicontepec formation

Upper Cretaceous
- Tamesí formation
- Mendez shales
- San Felipe formation

Lower Cretaceous
- Tamaulipas limestone
- Tamasopo limestone

LOWER CRETACEOUS

TAMASOPO LIMESTONE

The Tamasopo limestone is of Cretaceous age. Neither its contact on underlying beds, nor its exact relation to the Tamaulipas limestone above, has been observed. It is in excess of 2,000 feet thick, but no information as to its exact thickness is available. The name Tamasopo, derived from the town of Tamasopo, in the state of San Luis Potosi, has long been used for the producing horizon in the Tampico district, and has long been thought of by operators as the goal for which all wells start. Little is known of the complex struc-

[1] E. T. Dumble, *Proc. Cal. Acad. Sci.* (4), Vol. 8, No. 4; E. DeGolyer, *Trans. Amer. Inst. Met. Eng.*, Vol. 52 (1915).

ture and stratigraphy of the Tamasopo canyon. It is now known that the producing horizon of our south fields, to which the term Tamasopo has also been applied, is the same limestone which outcrops at El Abra in typical exposure. Tamasopo will be used here to designate the limestone which outcrops at El Abra, on the San Luis Potosi Railroad, and which is the producing formation of the line of fields extending from Dos Bocas, through Tepetate, Amatlan, Cerro Azul, and Potrero del Llano to Alamo. Its relation to the beds outcropping in the Tamasopo canyon is a matter which will have to be worked out later.

The Tamasopo limestone is a gray to white, pure limestone. It is massive and shows few, if any, bedding planes either in outcrop or in fragments blown from the wells. Much of the limestone carries abundant Foraminifera and in places is rich in rudistids. It has the appearance of a reef deposit. Both on outcrop and in the wells it is full of crystalline cavities, and at exposures in the vicinity of El Abra there are numerous large caves. The crystalline cavities, as seen in the samples blown from wells, are of all sizes, and in some places so small and abundant as to give the rock a pitted appearance.

TAMAULIPAS LIMESTONE

The Tamaulipas is also Cretaceous and belongs to the Comanchean series. It has been found lying directly on beds older than the Tamasopo but is believed normally to overlie the Tamasopo unconformably although the exact relation of these two formations has never been definitely determined. The base of the Tamaulipas has never been observed in the field, but from observations on its outcrop it is thought to be more than 2,000 feet thick. The San Felipe beds overlie it, apparently with slight unconformity, the contact being marked by an abrupt change in the character of the beds, but with no pronounced evidence of angular unconformity. The Tamaulipas limestone outcrops typically in the Sierra Tamaulipas and in the first ranges of the Sierra Madre, west of Ciudad Victoria, and is given the name of Tamaulipas on account of its abundant occurrence and typical development in the state of Tamaulipas. It has also been observed in the front ranges of the Sierra Madre, from Tamazunchale to a point southeast of Coyutla, where its characteristics and its rela-

tionship to the overlying San Felipe are unchanged. It is found in the wells of the Panuco-Cacalilao district at depths ranging from 1,650 to 3,000 feet. The commonest producing horizon at Panuco is the upper 50 feet of this formation, although important wells have been found as deep as 240 feet below the top, and a few less important wells have been brought in as deep as 400 feet in the formation. The Tamaulipas is so readily distinguishable from the overlying San Felipe that geologists have found its top to be the most reliable key bed upon which to map structure in the Panuco fields.

The Tamaulipas formation is a fine-grained, compact limestone with well-marked bedding. The uppermost 200–300 feet is predominantly gray in color and contains a large number of chert lenses and nodules of irregular shape. The color of the cherts varies from black to almost white. The lower part of the formation consists of creamy to white compact limestone. Cherts are practically absent in this lower part, but where found are rather of the nature of white or clear flints.

UPPER CRETACEOUS

SAN FELIPE FORMATION

The San Felipe formation is named from the station of San Felipe, on the Mexican National Lines Railroad between Tampico and San Luis Potosi, in the state of San Luis Potosi. It is of Upper Cretaceous age, and has an average thickness of 700 feet. Although its contact with the underlying Tamaulipas, both in outcrop and in wells, never shows evidence of pronounced unconformity, subsurface evidence within the Panuco field indicates that the San Felipe is not always conformable on the Tamaulipas. Limestones in the lower half of this formation are often prolific oil-producing horizons. A remnant of the San Felipe is thought to exist above the Tamasopo and beneath the Alazan shales in Tepetate, Alamo, etc.; there appearing in the wells in these fields some 100 feet of argillaceous limestone very like the San Felipe in appearance, and usually referred to the San Felipe by geologists. Absolute proof of the age of these beds is lacking, but there is good reason for making the correlation.

The San Felipe beds vary distinctly in several horizons from top to bottom of the formation. They also differ slightly in their lateral extension, changing from a complete limestone facies to a rather

argillaceous type of deposit. The basal part of the series consists of dark to black shales, with interbedded hard gray or brown flaggy limestones. These limestones have an earthly appearance on fracture, and are clearly distinguishable from the compact underlying Tamaulipas beds. The basal part of the formation usually carries dark cherts. The black or dark-gray shales disappear about 300 feet above the base of the series, and give place to about 100 feet of gray, or greenish-gray, thick-bedded limestones, with a few thin gray shales or partings, but this horizon takes on a more distinctly shaly or argillaceous character in some areas than the foregoing description would indicate.

Alternating hard gray shales, and thin-bedded limestones which vary from hard, fairly compact, to softer, marly limestones, make up the uppermost 300 to 400 feet of the formation. These beds are just as variable in lateral extent as they are changeable in the vertical section. The uppermost part of the formation is transitional, and grades into the overlying Mendez. In fact, in some areas true Upper San Felipe had distinct Mendez characteristics, and conversely in other localities a considerable part of the basal Mendez has recognizable Upper San Felipe attributes. A distinct darkening in color of the beds is a surer guide for fixing the top of the formation than the extremely variable presence, or absence, of true limestones. Soapstone, a material similar to bentonite, is common throughout the formation, and thin beds of crystalline limestone occur usually near the top.

MENDEZ SHALES

The Mendez formation, of Upper Cretaceous age, outcrops at the station of that name in the state of Vera Cruz, on the railroad between Tampico and San Luis Potosi, only the top of the formation being exposed at this point. The formation has a thickness of approximately 1,100 feet. It overlies conformably the San Felipe formation, and is overlain by the Tamesí formation. It is penetrated from top to bottom by practically all of the wells in the Panuco-Cacalilav district, and is well exposed in outcrop at various points along the east and west flanks of the Sierra Tamaulipas, south of the Rio Soto la Marina. It has been observed in the front ranges of the Sierra Madre, from Tamazunchale to Necaxa River, and its

thickness and characteristics are about the same from Soto la Marina River in the state of Tamaulipas, on the north, to Necaxa River in the state of Vera Cruz, on the south.

The Mendez shales are blue gray in color, massive, with very indistinct bedding planes, and tend to weather in splintery fragments, or in conchoidal lumps. The uppermost part of the formation consists of a distinct reddish horizon varying from 30 to 100 feet in thickness. Except for the difference in color, these red beds are very similar to the blue-gray part of the series; the splintery form of weathering, however, is absent; and joint planes are not so prevalent as lower in the formation. A few small lenses, 1 or 2 centimeters thick, of marly limestone, apparently made up of Foraminifera, are sometimes present in the red shale zone, as well as lower down in the series.

The Mendez north of Tampico, toward the Rio Grande, thickens considerably and loses some of the characteristics of its type locality. The red beds disappear and the shale, on the whole, becomes darker. This formation from its outcrop in Northern and Northeastern Mexico, in the Papagayllos Hills, has been called Papagayllos and the two terms have been used somewhat interchangeably—some geologists even applying the term Papagayllos to shales in the Tampico district overlying the San Felipe. Also, it has been thought that the Papagayllos included Mendez and Cretaceous shales higher than the Mendez; however, available evidence, at the present time, has established the fact that Papagayllos is in reality Mendez, and the formation name Papagayllos has been dropped in the Tampico district.

TAMESÍ FORMATION

Tamesí is the new name given to a formation which immediately overlies the red beds of the Mendez. It is Upper Cretaceous in age, has a thickness of at least over 1,000 feet, and is abundantly exposed from the railroad station of Velasco, in the state of San Luis Potosi, on the southwest, northward over the whole basin of Tamesí River, and as far north as the headwaters of Guayalejo River, in the state of Tamaulipas. This formation or its equivalent undoubtedly exists much farther north, through the whole of the Linares Basin, but up to the present time this area has not been thoroughly studied.

The base of the formation consists of gray and red shales, somewhat softer and less limy than those of the Mendez, which on weathering show a lighter color. Higher in the formation sandstones become somewhat prevalent.

The lower beds of the Tamesí formation have been studied in outcrop and encountered in wells in the vicinity of Ebano and Limon, state of San Luis Potosi.

A part of this formation in northern Tulillo, state of Tamaulipas, in the *municipio* of Magiscatzin, and around the station of Xicotencatl, contains sandstones from 6 inches to 2 feet thick. They are regularly bedded, fine grained, and quite hard.

EOCENE

CHICONTEPEC FORMATION

The Chicontepec formation, of Eocene age, outcrops at the town of Chicontepec, and over the whole of the area west of Calabozo-Platon River and east of the Sierra Madre. A typical section of it is exposed on Platon River, near Las Trojes, from just below Platon Sanchez southwestward across the strike to the foot of the Sierra Madre at Tamazunchale, where the formation lies on the Mendez. Although all of the shales and sandstones occurring between Platon and Tamazunchale have been referred to the Eocene, it is possible that a remnant of Upper Cretaceous is present between the Mendez and the Chicontepec, and that the dark shales with occasional sandy beds which are now assigned to the base of the Chicontepec may be of Cretaceous age, and more properly referable to the Tamesí formation. Our knowledge of the base of the Chicontepec is incomplete, and it does not seem probable that the Tamesí formation is missing over all the country lying at the foot of the Sierra Madre.

The Chicontepec at its type locality consists of dark shales which weather brown, alternating with bluish, fine-grained, brown-weathering sandstones, in beds from a few inches to 3 or 4 feet thick. The upper part, which is known to be of Tertiary age, has a maximum thickness of about 4,000 feet. Its exact thickness cannot be stated since key horizons have not been distinguished, since the structure on its outcrop is complex, and since the entire formation has never been penetrated in a well.

TEMPOAL SHALES

The Tempoal shales are typically exposed in the bluffs of Tempoal River, just below the town of that name. They cover the whole of the east side of the Tempoal Valley, from Tempoal to Platon Sanchez.

These shales are dark blue or dark brown on fresh exposure and weather yellow to brown. Although the formation consists principally of shale, it contains a few thin, inconspicuous sandstone beds, occasional ledges of oyster shells, and thin beds of Foraminifera. Ironstone concretions are characteristic. The maximum thickness is in excess of 2,000 feet.

TANTOYUCA FORMATION

Capping the hills east of Platon are limestones, sandstones, shales, and conglomerates, which represent the base of the Tantoyuca beds. These beds occupy all of the territory eastward to the vicinity of Santa Maria Ixcatepec.

Near the base of the Tantoyuca there are occasional lenses of loose, unconsolidated, calcareous grit, some of which attain a thickness in excess of 50 feet. The base of the formation is composed of impure limestones, conglomerates, and grits, with friable sandstones alternating with blue shales, which weather yellow to bright brown, in the middle and top of the formation. The top of the Tantoyuca beds may best be considered as appearing east of Santa Maria Ixcatepec, at which place the flaggy sandstones become inconspicuous, and the material is predominantly blue clay weathering yellow. Very little is known about the thickness of the Tantoyuca beds, as their occurrence does not permit of measuring the section. However, their maximum thickness is undoubtedly over 3,000 feet.

ALAZAN SHALES

The Alazan shales overlie the Tantoyuca beds and outcrop over the territory eastward to the type locality on the Alazan property, and as far north as the valley of the Tanquichin. They are predominantly blue-gray shales, weathering yellow, with occasional very thin sandstones. Samples of these shales from wells in the Tepetate-Cerro Azul district indicate a thickness of 2,000 feet or more.

OLIGOCENE

MESÓN FORMATION

The Mesón formation, of Oligocene age, overlies conformably the Alazan formation, the nearest approximation to a contact being displayed in the base of the hills at the type locality of the Alazan, on the Alazan property. This formation is more than 1,000 feet thick.

The Mesón beds, near the base of which there are characteristic fossil horizons, are made up of gray and yellow sandy clays interbedded with some sandstones and sandy fossiliferous limestones, all of which weather to a yellow color.

MIOCENE

TUXPAM FORMATION

Beds which have been referred to the Oligocene but which are now generally recognized as Miocene overlie the Mesón beds unconformably near the town of Tuxpam, state of Vera Cruz, and occupy the area between the outcrop of the Mesón formation on the Hacienda Mesón and the Gulf of Mexico.

At their type locality near Tuxpam these beds, like the Mesón, are predominantly yellow, although on a fresh, unweathered surface their color is gray. They consist of gray shales and frequent beds of sandstone and limestone. The harder beds do not appear to persist over wide areas. The entire series is probably over 1,000 feet thick.

These beds, as well as the underlying Mesón, fail to reflect the Cretaceous folding, and as a rule do not enter into problems of stratigraphy with which petroleum geologists are confronted. Therefore, they have not been studied to the extent that other formations have.

RUMANIAN OIL FIELDS

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ABSTRACT

The distribution of the Rumanian oil fields is governed by lines of folding related to the major Carpathian overthrust faulting. Along these lines of folding, the production tends to focus around salt masses that form local "highs." The source of the salt is unknown. Its rise is due to lateral pressure. The source of the oil is disputed, but the writer believes that it is Pliocene.

A comparison of these fields with those of the American Gulf Coast region shows that, although there are some resemblances which may indicate the action of like causes to a limited extent, the dissimilarities are greater. The lateral pressure, which is proved for Rumania, cannot be accepted as the entire, or even as the major, cause of the American domes.

INTRODUCTION

Geologists working on the problems of the Gulf Coast salt domes have drawn their European analogies mainly from the North German salt region. The occurrence of the salt in Germany has been adequately described in available publications. It differs from that in the American salt domes in the presence of associated "mother-salts" and the lack of any considerable oil production. The greater similarity of Rumanian conditions has been recognized but, on account of the lack of detailed information, the references have been vague or scanty. The following summary of the Rumanian oil region, as it is understood today, is written to show in what respects a comparison might be helpful.

The kindness of the Rumanian geologists, particularly Professor Murgoci, enabled the writer to go over most of the reports on these fields during three months spent in that country. It is mainly as a compilation of this material that the present article is written.

The region discussed comprises the old Rumanian provinces of Wallachia and Moldavia. Although there are prospects in Transylvania, those two provinces compose the entire oil-producing area of the country.

AREAL GEOLOGY

The region is divided into three zones. On the north and west, the Carpathian mountain system is composed of crystalline meta-

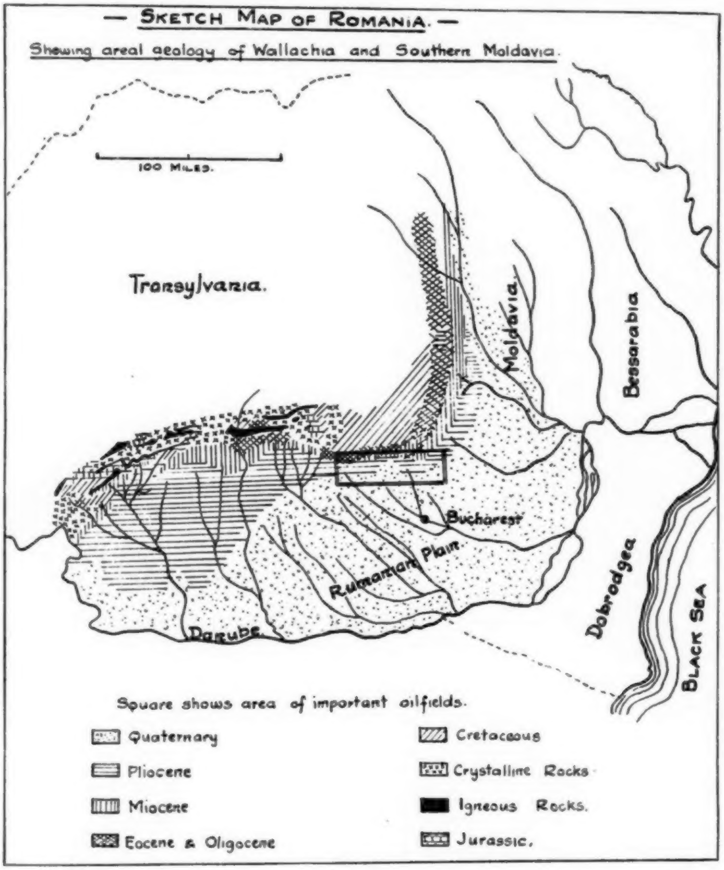

FIG. 1

morphic rocks with igneous intrusions, and of twisted and distorted remnants of Jurassic and Cretaceous sediments. On the south and east lies the Rumanian Plain, formed by the horizontal beds of

the Quaternary. Between these two zones, the broad band of foothills marks the area of folded Tertiary strata.

STRUCTURAL GEOLOGY

Great overthrust faults are the dominant structural features. They are explained by the position of the region on the eastern edge of the great Alpine movements. When, from overloading or other cause, the portion of the earth's crust composing the Greater Alps attempted to expand laterally, it encountered resistant earth masses. As a result, the outer edges of the expanding crust were out and over the stationary masses in great sheet overthrusts or "nappes." One of these movements occurred in mid-Cretaceous time, forming what are known as the "crystalline nappes." Another in mid-Miocene formed those distinguished as "Flysch nappes." This overthrusting was also of importance in its tendency to predetermine the type and direction of later movement.

The post-Pliocene Carpathian movement had the greatest direct effect on conditions in the oil region. With the appearance of the Carpathian Mountains during this interval, a series of paralleling folds was formed throughout the Tertiary belt. These folds extend for great distances but are so frequently broken by the steep plunging of the axes that they might be considered as chains of separate anticlines. At the same time that these were formed, salt masses appeared at the surface, most of them coinciding with the structural highs of the folds.

STRATIGRAPHY

The stratigraphy of the Cenozoic formation is given in some detail because of their relation to the occurrence of the oil:

QUATERNARY

Recent—Gravels, loose clays, and sands.
Pleistocene—Gravels and loess.

TERTIARY

Pliocene

Levantine—Yellow gray, clay, sands, and gravels.
Dacian—Gray to brown and black shaly marls, lignite beds, and several loose sands.

Pontian—Light greenish-blue marls, very little sand.

Maoetian—Slate-colored marls darkened with organic remains, with very softs andstones. (This description applies only to certain areas in the vicnity of the oil fields.)

Miocene

Sarmatian—Basal conglomerates and sandstones, and dark blue marls with thin gypsum beds.

Tortonian—lacking in most places, some thin limestone fragments.

Helvetian—Blue-gray marls and soft sandstones, gypsum, and dacitic tufa.

Burdigalian—Conglomerates and transgressive sandstones.

Oligocene

Upper—Massive porous sandstone.

Middle—Black disodylic[1] and menelitic[2] shales, very carbonaceous, but showing considerable diagenetic menelite, hornstone, and amber. (The same shales are regarded as source beds of the Galician oils in the north.)

Lower—Gray marls and soft sandstones.

Eocene

Sandstones, one massive and porous, gray marls, locally black or violet red.

The beds below mid-Cretaceous are of marine origin. Between these and the mid-Miocene, the formations are deposits from alternating mediterranean seas. Above these, the upper Tertiary beds were deposited by a succession of great "lakes" of variable salinity.

SALT

Distribution of salt.—The salt masses are scattered from the edge of the Quaternary across the mountains into Transylvania. Although they cannot be limited to any given geological area, the maximum occurrence of the salt masses coincides with the edge of the nappes (16),[3] and they tend to fall into general lines curving parallel to the Carpathians. The presence of unknown masses under the great thickness of recent beds in the Rumanian Plain is not unlikely.

The stratigraphic location of these masses is uncertain. Their position, piercing the youngest Tertiary beds, dates their appearance as post-Pliocene, but their base is unknown. No given formation has been proved definitely to be below them.

[1] A local term for black flint, hornstone, etc.

[2] Menelite is an opaque variety of very dark opal in these shales.

[3] Numbers in parentheses refer to bibliography at end of article.

The majority of these masses lie on lines of uplift, but there are exceptions. A few occur in synclinal areas or cutting at right angles across anticlines.

The masses are most numerous along the edges of the overthrusts, but the great interest lies with those appearing as "salt domes" in the outer, oil-bearing belt. These "domes" are found on the lines of post-Pliocene folding which extend in a series across the Tertiary belt to disappear under the Quaternary. The Tzintea, Baicoi, Floreshti, Moreni, Gura-Ocnitzei structure is a typical example of such a fold. It is known only by these long domes lying in a curved line, with their probable connections buried under flat alluvium. Salt masses have been found in four of these anticlines and oil in four; the most important of the oil fields, Moreni and Baicoi, have salt "cores."

Form of the salt.—On the surface, salt springs and ponds are the most characteristic markings of these masses. Mounds of the Gulf Coast type are unknown. Occasionally the surface above a dome is pitted by numerous shallow basins ("dolines").

The masses are roughly ellipsoidal, with their greater horizontal axis parallel to the direction of the fold, even curving with it. The sides are flexed but more or less vertical, one side usually showing the typical overthrust lip at the top. Thus the wells on the overthrust side pass from the recent beds into the salt and go through that before reaching the Tertiary formations and production. The thickness of the salt here increases as the main body is approached. All tests in the main part of the core have been abandoned, still in the salt; depths of more than 1,800 feet were recorded. On the opposite side, wells that start in the salt never pass out of it, and those nearby seldom strike it. Occasionally one reaches a bulge down on the side and even passes through it. This is likely to show a considerable thickness of salt (700–800 feet), and yet the adjoining wells find nothing, showing that the projection was flexure curving only slightly from the vertical.

Mrazec named these structures with salt "cores" "diapyr folds," a term based on the supposed mode of formation rather than the resulting form. With many inclusions, this term has become ambiguous.

Composition.—Chemically, the salt is almost pure sodium chloride (98–99.9 per cent), but many impurities in the form of clays, sands, and carbonaceous material have been folded in mechanically. Although scattered more or less throughout the mass, this débris occurs in greatest quantities near the top. It shows the same wavy lines of rock-flow type described in other countries.

Gypsum and anhydrite fragments may be found with the débris, but their only known occurrence as beds is where they are in place in the Helvetian formation that adjoins the mass. There is no definite layer of such material associated with the salt body, which might be compared to "cap-rock."

The reported occurrence of carnallite in the vicinity of Targu Ocna (11) constitutes the sole indication of mother-salts. Sulphur springs are common, some near the masses, but there is no apparent correlation.

Theories concerning salt.—The distribution of the salt masses, mainly on lines of uplift but with some in other positions, can be explained if it is supposed that the salt bodies, prior to the movement that brought them to the surface, were scattered irregularly throughout the region. During the formation of the folds, the pressure was temporarily great enough to cause the salt to flow. Most of the salt masses in this semi-fluid condition could migrate along their plane to the points of greatest relief, the major tectonic lines. And it is along these lines, with or without previous faulting, that the most favorable conditions were found for the ascension through the overlying beds to the surface.

Formation of the salt by precipitation from ascending solutions is precluded by this supposition. Its rise as a solid, but plastic, body is proved by its flattened, undulating form, by its position in the folds, curving back to the adjoining beds under its overthrust, and by the pinching of strata remnants in little synclines on its top. The synchronous appearance of the domes throughout the country in post-Pliocene time may be taken as confirmatory evidence. Even the great amount of sand, clay, and so forth, twisted into them accords well with this.

Lateral pressure is indicated clearly as the force which caused this rise. It caused the great Alpine movements of the earlier periods,

which had predominant influence even in this outlying region, where it was less intensive and the results not as clearly marked. The asymmetric anticlines and great reverse faults show that the Carpathian movement, during which the salt appeared, had the same origin. Finally, its effect is shown by the shape of the masses themselves, flattened and with overthrust lips.

There are several hypotheses as to how lateral pressure produced this rise. Those who attribute the greatest importance to the formation of the nappes in explaining the geology would look on this as the result of a similar phenomenon. The hypothesis would be that great reverse faults brought the salt, in its natural stratigraphic position, to the surface, where it was above the uppermost bed of the downthrust side. Then in the reaction from this overthrusting there would be a movement in normal direction, and the upthrust beds would sink back toward their former position. The salt, however, being more plastic, would be pinched in the fault area and remain at the surface, surrounded by younger beds.

The form of many "domes" falls in excellently with this theory, even having the lip overthrust in the direction of major movement, although there are some cases where it goes the other way. Thrust faults are practically universal, but while certain domes have a much older formation on the upthrust side, there are many with the youngest Pliocene formation on both sides, necessitating the complete return of the enormous throw (equal, at least, to the thickness of all Tertiary and Mesozoic strata) which would be necessary to raise the salt to the surface. This might be avoided, however, by postulating an upward movement of the salt in the fault planes. The exceptional cases, where the masses come to the surface at other points than the center of the structure, are not easily explained.

Kraus has advanced an interesting hypothesis. By the resolution of a force, such as the downward push of a settling area, he obtains a lateral thrust which follows a logarithmic curve. Shaw's Mississippi mud lumps are used as an example of such action at present. As Kraus points out, the characteristic form of the salt masses approximates the mathematical result as closely as could be expected when allowance is made for the other factors.

Although there is a lack of definite statements in the litera-

ture, it is probable that the majority of the geologists believe that the salt, at the lines of folding, found the least pressure from above and so moved in that direction.

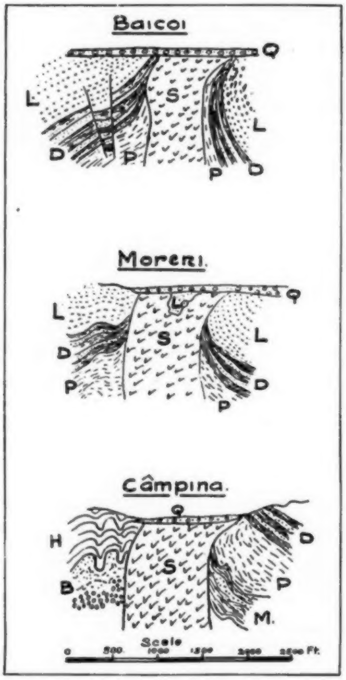

FIG. 2.—Cross-sections of typical Rumanian oil fields. *Q*, Recent; L, Levantine; *D*, Dacian; *P*, Pontian; *M*, Maoetian; *H*, Helvetian; *B*, Burdigalian; *S*, Salt.

The origin of the salt is unknown. It is generally regarded as coming from deposits in marine formations. Prior to the last five years, it was firmly held to have originated in the receding mediterraneans of the Miocene, therefore known as the "Salifere." This opinion is still held by some (1), although recent work has generally discredited it. But nothing has been found to show the actual source.

P. Voitestiti (16–19), whose work has been most important on this phase, after freeing the salt from its traditional place in the Miocene, moved the source down successively through the Cretaceous and Permian, until finally he suggested a precipitation on the cooling earth-crust as a possible origin. The vulcanists, from the days of Coquand (2), one of the earliest workers on these problems, have claimed that it is from emanations of volcanoes as yet unknown in this region.

OIL

Occurrence.—All the production comes from the Tertiary of the sub-Carpathian region, although signs of petroleum have been found in the Cretaceous and lower Tertiary in the mountains. Of this production, about 3 per cent comes from the Middle Tertiary of the northern curve (Moldavia), the rest from the Pliocene of the

southern curve, the district of typical "salt dome" oil fields. Because of fracturing, traces of oil have been found in practically every horizon. All the production, however, is limited to the Kliwa sandstone of the Oligocene, and the Maoetian and Dacian horizons of the Pliocene; over 95 per cent of the total, roughly, is divided between the last two.

Attempts have been made to differentiate the oils from the different horizons by their composition, but aside from the general tendency of Dacian oil to be heaviest, nothing has been shown. There is more difference between fields than between horizons.

All the oil is produced from well-marked uplifts. Those with salt "cores," being the areas of greatest folding, are the locations

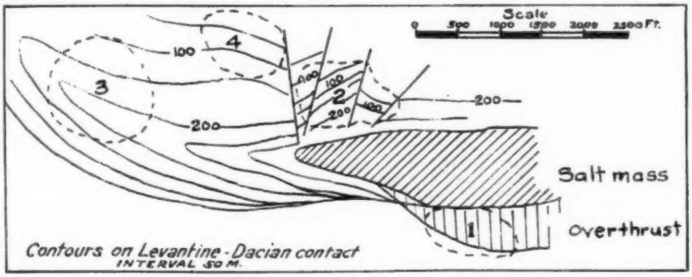

FIG. 3.—Sketch of Baicoi. Producing areas: (1) Schela Veche, (2) Cotoiu, (3) Ferbatori, (4) New Extensión.

of maximum production. All the region is heavily faulted. The faults, together with minor irregularities of bedding, have a local influence on the distribution of oil on the fold. Great emphasis has been laid on these faults in connection with the migration theory, which would make them the essential factors for the presence of oil, and the fold merely an aid in retaining it.

Figure 3, showing the Baicoi field, gives an example of areas of production on one of these anticlines with a salt "core," and indicates the focusing effect of the major structure, and the irregularities induced by faults and minor phenomena.

The relation between salt and oil has been greatly stressed in Rumania. Mrazec considered the presence of salt, either solid or in solution, as the absolute requisite for the formation of petroleum, the

oil here coming from "bituminous aureoles" formed about the masses. More recently, the adoption of the migration theory has led to the belief in the ascension of the oil along paths opened by the salt.

Practically, this has aided the efficiency of Rumanian oil geology. Although producing fields exist on simple anticlines in this region, by far the greatest amount of production comes from those inclosing salt masses. The heightening of the uplift, induced by the presence of the salt, correspondingly increases the likelihood of production. Thus the presence of salt is always of interest, and in cases where only flat recent terraces are exposed, the indications of such a mass give the best reasons for exploration. Murgoci's recent work at Floreshti gives an excellent example of the discovery of a salt mass solely from topographic evidence.

Source of the oil.—The source of the oil, like that of the salt, is a matter of contention. Mrazec's theory of origin about the salt mass named the Miocene strata, included with the masses as Salifere, as the source beds. This was generally accepted in spite of the absence of organic material in these strata. Migration was given as the cause of its appearance in horizons both above and below these. When opinion changed with regard to the source of the salt, this position was abandoned, and the oil source beds were looked for elsewhere.

P. Voitesti, in moving downward the source of the salt, continued to seek farther down for that of the oil. Although he does not place it definitely, the idea is given that he favors another precipitation, this time of petroleum, on the pre-Archean crust. Murgoci (10) has turned definitely to vulcanism, a theory which has always had more supporters in Rumania than in America. Except for the statement by Galician workers that the Moldavian oil comes from the same Oligocene beds as does their own production to the north, the other writers are vague in regard to the source, but invariably lay stress on migration to account for its present position.

Although the consensus of opinion is against it, the writer is inclined to favor an endogenetic source, the origin of the oil in Oligocene, Maoetian, and Dacian formations where it is found.

Those who support the migration theory have presented considerable evidence. They point out that the fossils of the producing

formations are not marine types and that the presence of lignite beds in the Dacian shows fresh-water or deltaic conditions, while oil source beds in most of the world are considered as of marine origin. They show that the great amount of faulting would furnish the necessary migration planes. Unbroken anticlines are known where the Dacian is barren, and they claim, therefore, that this formation will be productive only where its upturned edge is pinched along the salt contact, where the oil has entered. In certain fields, the lower the sand, the larger the producing area and the greater the amount of oil produced. This fact has been mentioned as still further evidence that the oil comes from below.

In the writer's opinion, the endogenetic theory is at least equally applicable to the oil occurrences so far as they are known. This was originally suggested by an examination of the stratigraphic column, where clay and shales resembling, in their texture and carbonaceous content, the beds which are considered as the source of oil in American fields were found only in the producing formations. It seemed unlikely that oil should ascend from below and, merely by accident, find reservoirs there. Then, in certain fields, some of the sands are lenticular, and production has been found where the sand body is completely isolated from breaks that would give access to rising oil. Only one or two unbroken anticlines, and these comparatively small, have been tested. Although no oil was found in the Dacian, it was found in small quantities in the Maoetian, which is usually the greatest producer. The relative lack of success could be laid to the relative gentleness of the folds. As for the pinching of the upturned edges of the producing formations, which was considered essential for the presence of oil, this very pinching would seem to prevent migration down the slope of the strata from the salt contact as it has aided in preventing its escape up the slope.

Finally, although there is much yet to be learned, the adoption of this theory has the advantage of furnishing a much simpler working hypothesis.

RUMANIA AND THE GULF COAST

The chief similarity of the Rumanian oil fields to those of the Gulf Coast is, of course, the accumulation of oil on structures having salt cores. The salt is the same, practically pure sodium chloride, with extraneous inclusions and "rock flow" lines, and without the

potassium and other salts of the German deposits. It has appeared in its present position from a source that is also unknown. The resemblance of form of typical masses is limited to the fact that their surfaces are small in comparison to their great depths.

The differences arise from the incomparably greater movement which is manifest in Rumania. Thus there is a series of well-defined, steep folds throughout the region, instead of the normal low-dipping strata of the Gulf Coast, disturbed only in the immediate vicinity of the salt. The salt masses themselves have been flattened parallel to the anticlinal axes and overthrust above the steeper side. This deformation illustrates clearly the effect of the force which caused the rise of the salt on the mass itself, when it is contrasted with the unchanged, circular plugs of our own fields.

Whereas the upward movement of the Gulf salt seems to have occurred at various times, including the present, the rise of the Rumanian salt is restricted to the post-Pliocene interval.

There is no "cap-rock" in Rumania, such as that in the Gulf Coast. Lacking this, and with no covering but the loosely consolidated Recent beds, oil never accumulates on top of the salt.

CONCLUSION

Thus, a summary of conditions in this other region producing oil from salt-cored structures shows more disparity than similarity. It furnishes an example of a region where the "domes" evidently were formed by the force of lateral pressure, and the similarities which exist may show a certain amount of causal relationship. The preponderating difference, however, would justify those who believe that other forces are mainly responsible for the existence of the Gulf Coast domes.

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THE EFFECT OF ROCK FLOWAGE ON THE KEROGEN[1] OF OIL SHALE

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ABSTRACT

It has formerly been reported that the kerogen of oil shale could be converted to petroleum at elevated pressures. Recent experimental work by the authors on typical oil shales from Elko, Nevado and Grand Valley, Colorado to determine quantitatively the amount of oil produced when these shales were subjected to rock flowage at ordinary temperatures disclosed the fact that no free oil was formed under such conditions. In view of the results obtained there is reason for doubting the common conception that the kerogen of oil shales represents a stage in the transformation of organic material to petroleum.

INTRODUCTION

In connection with recent researches bearing on the relation of kerogen to the origin of petroleum, the authors have undertaken experiments relative to the possibility of oil being generated from oil shale as a result of pressure. The apparatus adopted was a slight modification of that employed by Adams and Bancroft in their well-known flowage experiments.[4] Similar experiments on oil shale have been previously conducted by McCoy[5] and Trager,[6] who reported that they were able to transform kerogen into oil by the application of pressure to the point of rock flowage. Inasmuch as their work was based upon qualitative rather than quantitative methods, it was deemed advisable to repeat the experiment and to determine the exact percentage of oil, if any, produced under these conditions.

[1] The word "kerogen" is a Scotch term applied to the complex organic constituents in oil shale. They are insoluble in organic solvents at ordinary temperatures and pressures, but upon thermal decomposition form soluble bitumens. Of late there has been some question as to the applicability of this term, but for the want of any better expression, it is used in this paper.

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[4] *Jour. Geol.*, Vol. 25 (1917), p. 597. [5] *Jour. Geol.*, Vol. 27 (1919), p. 252.

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APPARATUS FOR FLOWAGE EXPERIMENT

Spool-like cylinders machined from cold rolled shafting steel were fitted with steel plungers having broad disk-like heads (Figs. 1 and 2). The diameter of the bore of the cylinders was $\frac{1}{2}$ inch, and the thickness of the thinner part of the walls was 1 millimeter. Cylinders of oil shale with a length of $1\frac{3}{5}$ inches were carefully turned down on the lathe exactly to fit the bore of the spool. In the individual experiments the plungers were then inserted a uniform distance into the spool so that the cylinder of oil shale was brought into a central position. The apparatus was then placed in a Riehle testing machine and pressure raised by successive steps to the point of flowage (Fig. 3).

RESULTS OBTAINED FROM TYPICAL OIL SHALES

Experiment 1.—A sample of paraffin base oil shale from the 350-foot level of the mine of the Catlin Shale Products Company at Elko, Nevada, capable of yielding by destructive distillation 42 gallons of oil per ton, was turned down on the lathe into the form of a cylinder $\frac{1}{2}$ inch in diameter and a little more than 2 inches in length. The cylinder was then cut down to the desired length ($1\frac{3}{5}$ inches) and the end portions were crushed and pulverized to pass an 80-mesh screen.[1] A carefully weighed portion was then subjected to a chloroform extraction for a period of 3 hours in a slightly modified Soxhlet apparatus in order to determine the amount of soluble bituminous material present in the natural state. The shale cylinder was then subjected to consecutive increments in pressure until the thin walls of the spool were bulged out as the result of rock flowage. The successive steps of pressure increases and the time of each are shown in Table I. In this first experiment, the initial pressures employed were low because the pressure required to produce flowage was not known. Reference to Table II shows that similar low pressures were not used in the second experiment. There was no appreciable heat generated by the rock flowage. However, the flowage was very slow, and some heat may have been conducted away from the

[1] Inasmuch as it was observed that the percentage of soluble bitumen present is directly proportional to the degree of pulverization of the shale up to 80 mesh, it was deemed advisable to pulverize the shale to this mesh in all cases.

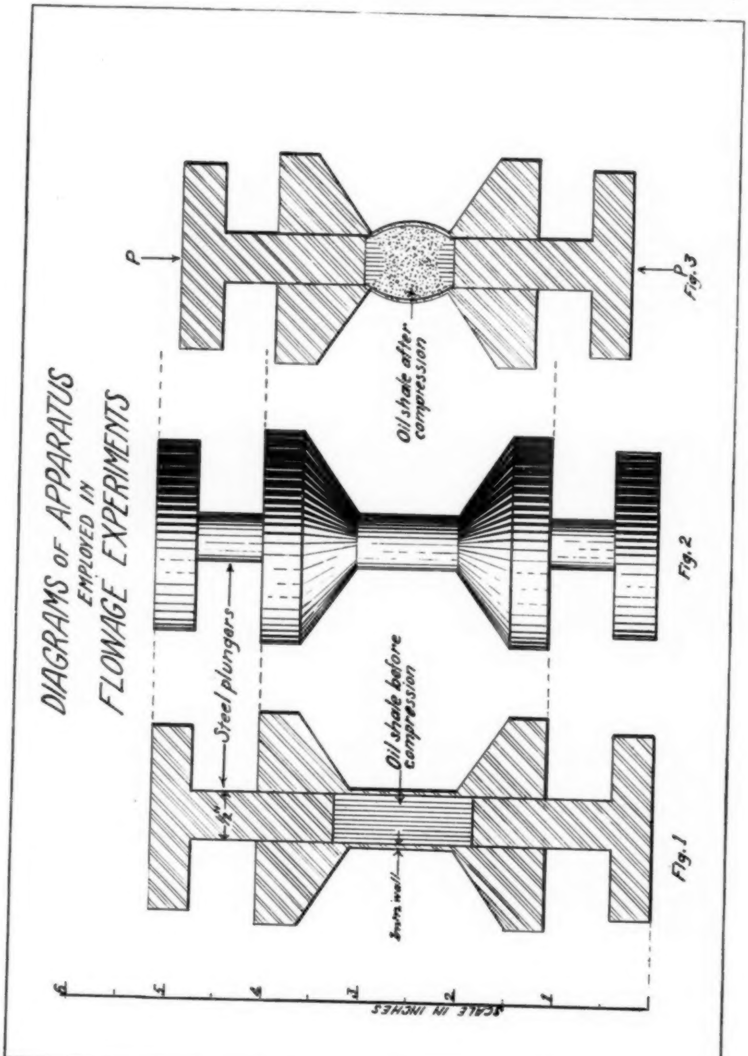
DIAGRAMS OF APPARATUS
EMPLOYED IN
FLOWAGE EXPERIMENTS
Steel plungers
Oil shale before compression
Oil shale after compression
P
P
Fig. 1
Fig. 2
Fig. 3
SCALE IN INCHES

TABLE I

HIGH-PRESSURE EXPERIMENT ON ELKO, NEVADA, OIL SHALE

Total Load on Cylinder as Recorded by Pressure Machine	Unit Pressure on Cylinder* of Oil Shale (Lb. per sq. in.)	Time in Minutes at Various Pressures	Total Time Specimen Was Subjected to Pressure		Remarks
			Hours	Minutes	
1,500..........	7,653	10	....	10	
2,000..........	10,204	15	....	25	
2,650..........	13,520	15	....	40	
3,000..........	15,306	10	....	50	
3,500..........	17,837	15	1	05	
3,600..........	18,367	5	1	10	
3,700..........	18,877	5	1	15	
3,900..........	19,898	5	1	20	
4,300..........	21,939	8	1	28	
4,500..........	22,959	5	1	33	
4,900..........	25,000	10	1	43	
5,100..........	26,020	5	1	48	
5,500..........	28,061	10	1	58	
5,700..........	29,081	5	2	03	
5,900..........	30,102	5	2	08	
6,400..........	32,653	10	2	18	
6,700..........	34,183	2	2	20	
7,000..........	35,714	13	2	33	Slight bulging
7,200..........	36,734	5	2	38	Slight bulging
7,400..........	37,255	2	2	40	Slight bulging
7,600..........	38,775	2	2	42	Slight bulging
7,800..........	39,796	3	2	45	Slight bulding
8,000..........	40,816	4	2	49	Distinct bulging
8,300..........	42,347	3	2	52	Rapid bulging
8,500..........	43,367	8	3	00	Cracks appeared

* Diameter of shale cylinder = ½ in. Area of head of shale cylinder = .196 sq. in. Pressure on shale cylinder = 5.102 multiplied by recorded applied load.

TABLE II

HIGH-PRESSURE EXPERIMENT ON GRAND VALLEY, COLORADO, OIL SHALE

Total Load on Cylinder as Recorded by Pressure Machine	Unit Pressure on Cylinder of Oil Shale* (Lb. per sq. in.)	Time in Minutes at Various Pressures	Total Time Specimen Was Subjected to Pressure		Remarks
			Hours	Minutes	
6,500..........	33,163	10	....	10	Incipient bulging
6,700..........	34,183	5	....	15	Incipient bulging
6,900..........	35,204	5	....	20	Distinct bulging
7,100..........	36,224	5	....	25	Distinct bulging
7,300..........	37,245	5	....	30	Distinct bulging
7,700..........	39,285	10	....	40	More rapid bulging
8,100..........	41,326	10	....	50	More rapid bulging
8,300..........	42,347	10	1	00	Cracks appeared

* Diameter of shale cylinder = ½ in. Area of head of shale cylinder = .196 sq. in. Pressure on shale cylinder = 5.102 multiplied by recorded applied load.

steel spool. The first noticeable signs of bulging occurred at a pressure of 7,000 pounds, corresponding to 35,714 pounds unit pressure. At this pressure and up to 8,000 pounds (equivalent 40,816 pounds unit pressure), the bulging proceeded very slowly. At the latter pressure, however, it became noticeable to the naked eye. In the final stages of the bulging, vertical cracks appeared in the middle portion of the spool.

On completion of the pressure treatment, the apparatus was removed from the pressure machine. The cylinder was then dissected and the flowed shale examined. The heads of the shale cylinder remaining in the flanged parts of the spool had undergone no appreciable change in physical constitution, but the middle part of the original shale cylinder was represented by flaky and pulverent material. Microscopic examination of the latter material did not reveal the presence of globules of oil or moist spots. It did show a greasy luster, but this has no significance, since the untreated shale has a similar appearance.

After pulverizing the flowed shale and passing it through an 80-mesh screen, a carefully weighed sample was placed in a modified Soxhlet apparatus and extracted with chloroform for a period of 3 hours. It was then taken out and dried to a constant weight at temperatures ranging between 80° and 90° C. in an electric drying-oven. The difference in weight before and after treatment represented the amount of soluble bitumen present. This was found to be 2.25 per cent. A sample of the original shale which was not subjected to flowage contained 2.34 per cent (see Table III). In extraction work of this nature, the differences may be considered to be within the limits of experimental error.

Experiment 2.—The second experiment was carried out under similar conditions with the same kind of apparatus, using a sample of mixed base oil shale capable of yielding sixty gallons of oil per ton, from Grand Valley, Colorado. The pressure was raised directly to 6,500 pounds, equivalent to 33,163 pounds per square inch. After standing at this pressure for about 2 minutes, bulging became noticeable. This pressure was held for 10 minutes, then it was increased by steps to 8,300 pounds, equivalent to 42,347 pounds per square inch (see Table II), at which point the bulging became rapid

and vertical cracks appeared in the middle portion of the spool. Horizontal cracks were also formed at the junction of the middle portion of the spool with the flanges above and below.

Upon opening the cylinder and examining the flowed shale, the latter was found to be identical in character with the shale of the preceding experiment, except that it was somewhat more pulverent. It showed no free globules of oil or moist spots.

TABLE III

CHLOROFORM EXTRACTIONS ON ELKO, NEVADA, OIL SHALE BEFORE AND AFTER ROCK FLOWAGE

Before Pressure	After Pressure
Soluble bitumen by weight = 2.34 per cent	Soluble bitumen by weight = 2.25 per cent

CHLOROFORM EXTRACTION ON GRAND VALLEY, COLORADO, OIL SHALE BEFORE AND AFTER ROCK FLOWAGE

<table>
<tr><th colspan="2">Before Pressure</th><th colspan="2">After Pressure</th></tr>
<tr><th colspan="2">Soluble Bitumen</th><th colspan="2">Soluble Bitumen</th></tr>
<tr><td>Calculated by loss in weight of shale = 1.95 per cent</td><td>Calculated by weight of extracted oil = 1.97 per cent</td><td>Calculated by loss in weight of shale = 1.97 per cent</td><td>Calculated by weight of extracted oil = 1.92 per cent</td></tr>
</table>

The extraction was carried out in the same way as in the preceding experiment, except that the loss in weight of the shale upon the extraction treatment with chloroform was checked by the weight of the soluble bitumen recovered (see Table III). The results again were negative. There was no development of free oil by the compression of the shale to the point of flowage.

CONCLUSIONS

The failure to produce free oil during the flowage of typical oil shales in the above experiments raises a doubt as to whether the shale used by McCoy and Trager, in their experiments in which they reported they were able to generate free oil as a result of pressure, was a true oil shale. Unfortunately, the source of their sample was not stated.

In view of the fact that the above experiments have demonstrated the improbability of free oil being formed from kerogen as such at elevated pressures and ordinary temperatures, the question arises as to the possibility of petroleum being genetically related to oil shales. The authors entertain the view that the original source material of both kerogen and petroleum may have been very similar in character, but that the details of the transformation of the source material into these substances may have been different. In other words, kerogen, in place of representing a stage in the transformation of organic material to petroleum, may be an independent product. However, our present knowledge does not justify sweeping conclusions regarding the relation of kerogen to petroleum. It is hoped that further researches will furnish more definite data bearing on this problem. The authors have additional experiments under way in which the flowage of oil shale is induced at temperatures above normal, but below the initial decomposition temperature of kerogen at ordinary pressures.

The authors wish to express their thanks to Professor W. P. Huleatt for assistance in conducting the flowage experiments, and to Mr. Bart De Laat for checking the extraction results.

GEOLOGICAL NOTES

GEOPHYSICAL SURVEYS AS AIDS TO THE GEOLOGIST

Of recent years much attention has been given by physicists to the perfecting of instruments to record minute differences in gravity and other physical quantities. The torsion balance has perhaps attracted most interest and has given the most striking results. By its use minute differences in gravity values can be determined; and when a number of results are plotted, a map showing isogams or lines of equal intensity encircling areas of low or high gravity is obtained.

This method has been used extensively in connection with petroleum work in the plains of Hungary and other countries, especially where the presence of salt domes is suspected. The low specific gravity of the salt masses gives very definite results, and thus areas of low gravity can be mapped out.

Where domes of older and heavier rocks are indicated, areas of high gravity can be delineated, and this is especially noticeable when a solid limestone is overlaid by ordinary sand and clay sediments.

The results have been in some cases so definite that drilling is being undertaken to test the underground structures that are indicated. There is at least one authenticated case of an oil field (the Egbell field) discovered by this method.

It is only in flat country that the torsion balance can be employed with confidence: hilly ground, or the presence of hills in the near neighborhood, causes so many complications that it is difficult to determine the normal local value of gravity, the divergences from which, either above or below, give the indications of concealed structure when plotted carefully and methodically on a map.

It will be noted also that it is at the best only geological structures that can be indicated: it does not follow that petroleum will be associated with any favorable structure that may be discovered.

In the coastal plain areas of Texas, Louisiana, and Arkansas—that is to say, the low-lying land that extends right up to the Palaeozoic outcrop—the oil and gas fields are probably all associated with salt domes, though in many cases these may be in an incipient stage of development and very deeply buried. It is true that in many of the proved fields no signs of an intrusive salt mass have been detected, but the general orientation of the fields and the distinct but very gentle structures that have been revealed by extensive drilling point to the probability of salt-dome action. The minor faulting that has occasionally been proved is also quite consistent with the salt-dome theory. Therefore, the discovery of an inclosed "minus" area, that is, where the isogams—the gravity contours, so to speak—are disposed in concentric rings about a locality where the gravity value

's below the normal, must be considered a very important step toward the finding of a new oil or gas field.

In countries or states where geological evidence at the surface is so scanty as to be almost negligible, the geologist must make use of every means to obtain information as to concealed structures, and the torsion balance, used in connec- with a geological survey, may enable astonishing results to be achieved.

There is happily another method that may be employed to confirm or supplement the evidence obtained from a torsion balance survey. It is well known that around some of the greatest oil fields there is a disturbance of the earth's magnetic field, both the directions and the spacing of the lines of equal magnetic variation being affected, and probably also the declination.

The writer pointed out some years ago that a mass of oil-impregnated rock surrounded by similar strata impregnated with water might be detected by plotting the density of the magnetic field, noting especially the vertical component. An oil-bearing area must necessarily be a poorer conductor than a water-bearing area, and thus the density of the magnetic field should decrease over an oil field. A careful magnetic survey made with very delicate instruments may give very clear indications of the presence of petroleum in quantity.

This method has actually been used in the last two or three years in certain European countries and has given remarkable results by plotting magnetic contours, closed minus and plus areas being delineated. The significance of such evidence has not yet been proved by experimental drilling on an extensive scale, but there is no reason to doubt the accuracy of the observations made.

Here then are two methods which can be employed in conjunction in land where surface evidence is at a minimum, the one to detect hidden structures and the other to detect concealed stores of petroleum. In cases where both indicate a definite locality, there is a prima facie case for an experimental well.

The plains of Hungary, Rumania, the southwestern states of the United States, and many other countries, afford ideal areas in which these methods can be tested, and without making any extravagant claims for either method we may be sure that interesting and possibly very important results will be obtained. The scientific geologist certainly cannot afford to disregard the help that geophysical surveys can give him when confronted with unreadable ground.

There have been many oil-finding instruments designed, and often extensively advertised in the past; all that the writer has personally seen are of the "doodlebug" type, more calculated to extract dollars from the pockets of the credulous than to fill them by pointing to where oil can be struck. But the methods briefly described above are founded on well-known and understood phenomena, and have been elaborated and perfected by men of high position in the scientific world. There can be no doubt that there is a future for geophysical surveys to supplement the work of the geologist in countries where surface evidence fails. In this connection a Hungarian scientist, Professor Rybar, is already undertaking the training of experts in the use of the torsion balance and other instruments, in order that they may be able to undertake expeditions to

different countries where, under the guidance of local geologists, they may make geophysical surveys. By such co-operation it is hoped that much that is now hidden in Nature's bosom may be revealed for the benefit of the practical exploiter of oil fields.

E. H. CUNNINGHAM CRAIG

September 25, 1924

GUIDE NOTES ON THE MIDWAY IN SOUTHWESTERN ARKANSAS

These notes are intended as an aid in locating and studying the Midway Eocene outcrop in southwestern Arkansas, by giving some of the localities where Midway beds have been recently identified, so that more definite and more extensive evidence may be gained of this formation, which hitherto has not been at all generally recognized in Arkansas southwest of the exposure near Malvern, Hot Spring County, described by Harris[1] in 1892 as "the most western known limit of the Midway stage in Arkansas."

During the past year, the marked increase of wildcat drilling in eastern Texas, from Mexia and Powell northeastward along the strike of the fault zone and even across the state line into southwestern Arkansas, has emphasized the importance of the ability to distinguish the Wilcox and Midway formations of Lower Eocene, and the Navarro formation of Upper Cretaceous, because of the fact that acreage was taken on evidence of favorable structures following the supposed line of faulting paralleling the Cretaceous-Eocene contact. The Midway has been one of the key formations in recognizing the supposedly favorable faulted conditions; consequently, as the lines of development moved eastward beyond the easternmost extent of Midway outcrop in Titus County, Texas, as most recently published by Thompson,[2] the difference of professional opinion regarding distinction of Midway from adjoining formations became a difference of opinion in regard to the very existence of Midway.

The Midway has generally been considered as absent, probably because of overlap, along the 150-mile strip of Cretaceous-Eocene contact from Titus County, Texas, to Hot Spring County, Arkansas. It must be stated, however, that the presence of Midway in Arkansas is indicated by Stephenson[3] on his map of this contact in the Atlantic and Gulf Coastal Plain, and in fact he says, "From the vicinity of Arkadelphia, Arkansas, southwestward to the Rio Grande, Upper Cretaceous deposits . . . . are overlain almost continuously by marine Eocene strata which Harris has correlated with the Midway."[4] Harris, however, has

[1] G. D. Harris, "Tertiary Geology of Southern Arkansas," *Ann. Rept. Geol. Surv. of Arkansas for 1892*, Vol. 2 (1894), pp. 32–33.

[2] Wallace C. Thompson, "The Midway Limestone of Northeast Texas," *Bull. Amer. Assoc. Petroleum Geologists*, Vol. 6, No. 4 (July-August, 1922), pp. 322–32.

[3] Lloyd William Stephenson, "The Cretaceous-Eocene Contact in the Atlantic and Gulf Coastal Plain," *U. S. Geol. Survey P.P. 90*, Pl. XI., 1914.

[4] *Op. cit.*, p. 157.

not described any Midway in Arkansas southwest of Hot Spring County, and Stephenson[1] himself, in his chapter on "Unpublished Details Relating to the Contact," does not mention any localities in the 150-mile strip here considered.

In Louisiana, the Midway has been, as a rule, more or less arbitrarily recognized in subsurface correlation—arbitrarily because there appeared to be room for it, lithologically, in the geologic sequence in spite of the rather widespread absence of diagnostic fossils. From some wells, however, cores have been obtained revealing recognizable Midway fossils,[2] and almost all published studies of Louisiana geology have accorded it a place, though lacking positive evidence.

Exposures of the formation in Louisiana are few. Harris[3] described Midway fossils from his "Many Dome" southwest of Marthaville, Sabine Parish, recently found however by Howe[4] to have been an error in correlation, and from King's Dome at Castor, Bienville Parish. In addition, field work[5] within the past year has indicated, on lithologic evidence, exposures of Midway on the following salt domes within the state: Bistineau and Vacherie in Webster Parish, and Prothro in Bienville Parish.

On the whole, however, the fact that no Midway had been described on the outcrop southwest of Hot Spring County, Arkansas, together with the general absence of well-known or fully satisfactory evidence of it, either in surface or subsurface geology in Louisiana, caused some geologists to be skeptical of its presence, particularly on the Sabine uplift and north of it in southwestern Arkansas.

Within the past year a number of collections made by different geologists working along the Cretaceous-Eocene contact in Arkansas have yielded Midway fossils from formations hitherto mapped and generally accepted as Wilcox Eocene and Arkadelphia Cretaceous.

In January, 1924, the writer made a small collection of fossils from marine beds at the base of Buzzard Bluff, Sec. 16, T. 14 S., R. 26 W., Miller County, Arkansas, and on subsequent visits collected more material, all of which was examined by Mary Jane Rathbun and J. W. Gidley of the U. S. National Museum, and by Julia Gardner of the U. S. Geological Survey. Among the undeterminable fossils were a *Cardium*, fish scales, and a shark tooth. Concerning the crustaceans submitted, Miss Rathbun reported in part as follows:

> The fossil claws belong to a burrowing shrimp, *Callianassa ulrichi* White (*Proc. U. S. Nat. Mus.*, Vol. 3 [1880], p. 161; Vol. 4 [1881], p. 137, Pl. 1, f. 10, 11). . . . . Harris (*Ann. Rept. Geol. Surv. Arkansas*, Vol. 2 [1892], p. 36) lists this species as from

[1] *Op. cit.*, p. 160.

[2] F. X. Bostick, paleontologist, Standard Oil Company of Louisiana: personal communication, 1924.

[3] G. D. Harris, "The Cretaceous and Lower Eocene Faunas of Louisiana," *La. State Geol. Surv. Rept. for 1899*, pp. 297–99.

[4] H. V. Howe, "The Many Salt Dome," this *Bulletin*, p. 170.

[5] W. C. Spooner, consulting geologist, Shreveport, Louisiana: personal communication, 1924.

the Midway stage of the Eocene. . . . . Two of the nodules contain a *Raninoides*, apparently the same species as a much larger specimen in the Museum, from the Basal Eocene of Texas. . . . .

The beds thus determined as Midway lie at the base of a 50–60-foot bluff whose upper part is mapped Wilcox by Veatch[1] and Harris.[2]

In June, 1924, the Shreveport section of the Southwestern Geological Society devoted its annual outcrop trip to a field study of the Cretaceous-Eocene contact in southwestern Arkansas, and as a result of this work, Howe[3] has published a definite announcement of the Midway discovery at the outcrop, reading as follows, after substituting the exact localities for the inaccurate general location mentioned in the text:

> [Two localities, one in the southeast quarter of Sec. 1, T. 12 S., R. 24 W., on the highway between Emmet and Hope, Hempstead County, and one in the northwest quarter of Sec. 26, T. 11 S., R. 23 W., on the highway between Emmet and Prescott, Nevada County, Arkansas], in what has heretofore been mapped as Arkadelphia, [were] visited by Mr. Paul T. Seashore, paleontologist for the Boyd Oil Company, Dallas, Texas. The writer was fortunate in being able to examine the truly remarkable collection of foraminifera which Mr. Seashore obtained from this material and is perfectly in accord with his opinion that it is Midway in age and not Arkadelphia.
>
> If this conclusion is correct, we are presented with the situation that the Arkadelpha cannot be more than 300 to 400 feet in thickness in this region, and that the upper portion of what has heretofore been classed on well logs as Arkadelphia is in reality Midway.

In addition to accepting Seashore's foraminiferal evidence, Professor Howe[4] presents the following list of fossils which he himself collected at the locality in Sec. 26, T. 11 S., R. 23 W., together with the note that "the presence of *Trochocyathus hyatti* and *Ostrea pulaskensis* render the age of these fossils certain as basal Midway":

MIDWAY SPECIES COLLECTED BY H. V. HOWE, SEC. 26, T. 11 S., R. 23 W., THREE MILES NORTH OF EMMET, ARKANSAS

Pelecypoda
- *Arca* sp.
- *Cucullaea* cf. *macrodonta*
- *Cucullaea* sp.
- *Leda* sp.
- *Lucina* sp.
- *Ostrea pulaskensis*
- *Yoldia* cf. *eborea*
- *Venericardia* sp.

Gastropoda
- *Caricella* sp.
- *Tornatella* cf. *alabamiensis*
- *Turritella* sp.

Anthozoa
- *Trochocyathus hyatti*

Shark teeth

[1] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geological Survey P. P. 46*, 1906, Pl. III.

[2] G. D. Harris, "Oil and Gas in Louisiana, with a Brief Summary of Their Occurrence in Adjacent States," *U. S. Geological Survey Bull. 429*, 1910, Pl. XII.

[3] H. V. Howe, "The Arkadelphia Formation (Stratigraphy)," *Louisiana State University Bulletin*, Vol. XVI, n. s., No. 5 (June, 1924), pt. 2, p. 5.

[4] H. V. Howe, professor of geology at Louisiana State University, Baton Rouge, Louisiana: personal communication, November 14, 1924.

A fourth outcrop locality which possesses a striking resemblance both lithologically and paleontologically to the Midway at Buzzard Bluff is at the clay pits of the Texarkana Pipe Works, in Secs. 4 and 9, T. 15 S., R. 28 W., Miller County. The lower part of the section exposed in these pits comprises at least 16 feet of shale beds containing bivalves and fish scales.

As these four localities of Midway and probable Midway exposures in southwestern Arkansas form a narrow strip, if connected, of only 40 miles in the middle of a long 150-mile line of probable Midway outcrop extending from Titus County, Texas, to Hot Spring County, Arkansas, not previously accorded recognition by geologists, they serve only as the starting-points for a great deal of work which must be done to establish the presence of this basal Eocene formation along the Cretaceous contact.

J. P. D. HULL

SHREVEPORT, LOUISIANA
November 19, 1924

"THE MANY SALT DOME," SABINE PARISH, LOUISIANA

The first reference to this locality (on the road from Marthaville to Many near Rocky Spring Church, northeast quarter of Sec. 24, T. 8 N., R. 11 W., on the Ranes place) was made by Hopkins,[1] who stated that a bed of *Ostrea georgiana* occurred there. That this oyster was not *O. georgiana*, a Jackson species, was pointed out first by Harris,[2] in his discussion of the Midway stage. Harris considered it to be *Ostrea crenulimarginata*, one of the most characteristic fossils of the Midway formation. In the same volume, Harris[3] described from this locality the following species of mollusks: *Ostrea crenulimarginata*, *Modiola stubbsi*, *Turritella mortoni*, *Fusus harrisi*, *Leiostoma* (?)*ludoviciana*. Harris[4] again referred to this locality in his report on the "Geology of the Mississippi Embayment," stating that it was Midway in age because of the presence of *Ostrea crenulimarginata*, and postulated a local uplift of from 1,000 to 3,000 feet at this place.

Veatch,[5] in discussing the "Salines of North Louisiana," did not specifically mention this locality, but his map of the salt domes of Louisiana and Texas (Plate XXIII) shows a salt dome here. Since then many writers, particularly Harris and Veatch, have referred to this locality as the "Many Dome" or the "Many Saline."

Recent discussion, at meetings of the Shreveport Geological Society, directed attention to this locality and Mr. W. C. Spooner, revisiting it, made exten-

[1] F. V. Hopkins, *Amer. Jour. Sci.*, Vol. 48, p. 342.

[2] G. D. Harris, *Ann. Rept. La. State Geol. Surv.*, 1899, p. 63.

[3] *Ibid.*, pp. 297–99.

[4] G. D. Harris, *Ann. Rept. La. Geol. Surv.*, 1902, p. 10.

[5] A. C. Veatch, *Special Rept. No. 2, La. Geol. Surv.*, 1902

sive fossil collections. His careful field examination failed to show any evidence of unusual local uplift. Moreover, wells drilled in this vicinity show a thickness of more than 1,300 feet of Wilcox sediments overlying the Midway.

The writer's study of the fossils collected by Mr. Spooner has shown conclusively that the large oyster determined by Harris as *Ostrea crenulimarginata* is in reality *Ostrea tasex*, a Wilcox species recently described by Dr. Gardner[1] from the Indio formation of southwest Texas. *Ostrea tasex* differs from *O. crenulimarginata* in having both valves decidedly ribbed, while *O. crenulimarginata* possesses ribs on the left valve only, the right valve being smooth.

It thus appears that all evidence for placing a salt dome at this locality has been effectively removed.

HENRY V. HOWE

LOUISIANA STATE UNIVERSITY
BATON ROUGE, LOUISIANA
November 14, 1924

WATERS FROM THE GREEN RIVER SHALE

Confusing evidence as to the origin of the Green River shales is not confined to paleontology and paleobotany. Waters obtained from wells drilled into this series are at least equally contradictory. Some of the wells in the Uinta Basin yield fresh water, some sulphur water, and some salt water, and in the only reasonably deep hole in the Basin, the Utah Southern–Ute Petroleum well southwest of Duchesne, fresh, brackish, sulphur, and salt waters have been encountered as follows:

72–73 feet	Black limestone carrying about 60 barrels an hour of fresh water, apparently coming through a crevice in the limestone.
315–319	Black sandstone carrying a small amount of sulphur water.
842–844	Fine gray sandstone carrying sulphur water.
2,606	Gray shale with strong salt water, rising about 75 feet in the hole.
2,692–2,732	Fine-grained sandstone with shale parting above the middle. Upper bench carries salt water; lower bench fresh water. Water rises about 2,100 feet in the hole.

This well is in the midst of numerous faults, and a number of oil and gas showings have been encountered.

MAX W. BALL

DEEP PINE ISLAND GAS

An entirely new producing horizon for the North Louisiana region, if not for the entire Gulf Coast area, was recently discovered by the Dixie Oil Company's well, Dillon No. 43, Sec. 13, T. 21 N., R. 15 W., Pine Island field, Louisiana. Since 1922, until about three months ago, this well had been producing

[1] Julia Gardner, *Prof. Paper 131, U. S. Geological Survey.*

from the chalk rock horizon, around 1,700 feet, when the production from that horizon became unprofitable and it was deepened from 2,668 feet with cable tools to the present depth of 3,623 feet. At a depth of 3,538 feet a small amount of gas was encountered in broken lime and shale. Every soft break in the lime from 3,538 to the total depth yielded additional gas. When the bit had reached 3,621 feet, the well was probably making 15,000,000 cubic feet of gas. The last two feet increased the amount to 36,000,000 cubic feet.

The closed-in pressure after flowing wild for 20 days was between 1,550 pounds and 1,575 pounds. A test made was for gasoline content by the charcoal method and showed 725 gallons per million cubic feet.

Arrangements have been made with the Arkansas Natural Gas Company to take the gas, which will be turned into the main line supplying Texarkana, Little Rock, and intervening towns.

In 1920 the Dixie discovered the 2,900-foot sand in Sec. 14, T. 21 N., R. 15 W., on the same farm as the present big gasser. Fossils from the 2,900-foot horizon were determined by Dr. Udden of Texas and Dr. Stanton of the United States Geological Survey as Glen Rose in age. Cuttings from the present gas well from 3,245 to 3,567 feet have been examined by a number of paleontologists for foraminifera, and while there has been some hesitancy in expressing opinions, the age has been variously placed from the Del Rio to the Permian.

Owing to the richness of the gas, other wells in the region will be drilled in an effort to locate a deep oil horizon, and it is hoped that additional evidence will be obtained to help determine definitely the age of the horizon from which the rich gas is now coming.

A. F. CRIDER

SHREVEPORT, LOUISIANA
November 18, 1924

THE WORTHAM AND LAKE RICHLAND FAULTS

Two photographs which have a bearing on the Mexia fault zone are presented. Figure 1 shows an exposure of the "Wortham Fault," which lies nearly a mile west of the north end of the "Mexia Fault," overlapping the latter *en échelon*. At this outcrop the Wortham fault brings sandy shales and sandstones carrying thin layers of lignite, probably of lower Wilcox age, against concretion-bearing clayey shales of middle or lower Midway age. The displacement is very likely several hundred feet.

This fault is of particular interest just now because of the recent discovery of oil in the Boyd Oil Company's Boyd No. 1 well, located one mile due north of the point shown in the picture. Credit for this location is due to the Geological Department of the Boyd Oil Company. This well was drilled about 2,000 feet west of the outcrop of the fault. It penetrated very little, if any, Austin chalk, proving a displacement of at least 400 feet. This discovery has initiated a very intensive drilling compaign in the vicinity of Wortham, in extreme western

FIG. 1.—Exposure of the Wortham fault, looking about N. 30° E., along its trend. At the left are steeply dipping sandstone and sandy shale beds; at the right, low dipping clayey shales, the inclination of which is parallel to the hammer handle. The steep dip is drag in the downthrown (western) block. Between the two sets of strata is a brecciated fault zone about 12 or 15 inches thick. Photo by F. H. L.

FIG. 2.—Cut and polished surface of a core of Austin chalk. Furnished through the courtesy of Mr. R. J. Graves. Photo by F. H. L.

Freestone County, where there are many small tracts leased by various individuals and companies.

Figure 2 shows a cut and polished core of Austin chalk, taken from a depth of 2,350 feet in the R. J. Graves et al. C. H. Graves No. 1, about three-quarters of a mile north and a little east of the north end of the "Lake Richland" field or "New Richland" field, in Navarro County, Texas. This dry hole was drilled through the fault which limits production on the west side of the Lake Richland field. The chalk was found to be of reduced thickness, but on the upthrown (east) side of the fault. The core was taken from the top of the chalk where this formation is intersected by the fault.

The specimen reveals many minor slips, many of which make an angle of about 60° with the axis of the core. In the figure this angle is reduced because the polished surface was made oblique to the direction of dip. The whole core is seen to be much brecciated.

F. H. LAHEE

DALLAS, TEXAS
November 24, 1924

TESTING AND ADJUSTING THE BINOCULAR MICROSCOPE AND SUGGESTIONS ON THE USE OF MICROSCOPES IN GENERAL

As the binocular microscope is coming more and more into use among petroleum geologists it seems worth while to publish in this *Bulletin* directions for adjusting this instrument that were prepared primarily for the use of the members of the U. S. Geological Survey.

A number of Survey men who were working with binocular microscopes were being seriously troubled by eyestrain. The question whether there are defects in these instruments was therefore taken up in conference with the optical instrument section of the Bureau of Standards. The information obtained as a result of this conference has led to the recommendations here set forth which have been approved by I. C. Gardner, chief of the Optical Instrument Section, U. S. Bureau of Standards.

Though apparently little is definitely known about the effect on the eyes of different types of microscopes and different conditions of their use, the prevailing opinion seems to be that the binocular microscope from its construction should be particularly easy on the eyes. But it is not unless it is in good adjustment. The following two tests and adjustments are considered sufficient.

1. *Concentricity of the fields of the two tubes.*—The fields seen with the two tubes should coincide exactly. Each of the paired objectives is held in place by three adjustable screws. To turn these screws use a 0.040-inch or 0.055-inch jeweler's screw driver, according to the make of the microscope. Draw a number of concentric circles with as fine lines as possible 0.5 millimeter or so

apart, the largest having a total diameter equal to the diameter of the field covered by the lowest power, about two centimeters. If the microscope has an adjustment for difference in focus of the two eyes, make this adjustment first. If the microscope has no such adjustment, correct it by wearing your glasses, if you use any, or have your correction lenses fitted directly to the eyepieces. To correct astigmatism it is necessary to use correction lenses, and this correction is probably important. All adjustments between the two eyes having been made, cover the field of one eye, focus the microscope carefully for the other eye on the circles, and center them in the field of that eye. Fix microscope and circles in this position. Then look at the circles with the other eye through the other tube, and if any eccentricity is found correct it by moving the objective with the adjusting screws. Always first release the screw or screws in the direction in which the objective is to be moved, then tighten the other screw or screws gently. Always check back on the first side before continuing the correcting of the second. Make this adjustment for each pair of objectives.

Any displacement of the center of the image of one of the sets of circles above or below a left-to-right line through the centers of the two fields, or outward, away from the other, is probably more injurious than a displacement inward, toward the other; but it is safest to adjust the objectives as perfectly as possible.

As the angle between the two objectives is fixed, focusing the microscope changes the point on which they converge and hence shifts the centers of the circles in the fields of view. It is therefore important to focus carefully before adjusting.

As a consequence, also, unless all the pairs of eyepieces used with the microscope have the same focus, putting in a different pair from that with which the adjustment was made will necessitate a readjustment of the objectives. Probably it would be best, until the makers take up the matter, to fit eyepieces with collars that determine their location in the tube, so that no refocusing of the microscope will be necessary when the eyepieces are interchanged. In any case it is advisable to make the adjustment with the pair of eyepieces most generally used, which should be of a rather low power.

2. *Parallelism of the prisms in the two tubes.*—To test the parallelism of the prisms it is necessary to have a line that can be carried parallel to itself from one eyepiece to the other. Probably the easiest way to do this is to use a telescope of low power (about $\times$ 4, if possible), with cross-hairs. Mount the telescope, as shown by the accompanying photograph, on an ordinary iron stand with upright rod, such as is used by chemists. The telescope should be clamped at the end of a horizontal rod rotatable about its own long axis and coming off from the upright rod in a direction approximately perpendicular to the vertical right-to-left plane through the centers of the two tubes of the microscope. A steel straightedge is fastened on the table on which the test is made, about parallel to this same plane, and the base of the stand is moved along this straightedge without rotation.

On account of the high magnification resulting from the combination of telescope and microscope a very fine line is needed in the field. The cross-hairs of a microscope eyepiece with the lenses removed from both ends and illuminated from below, as shown in the photograph, were found very satisfactory.

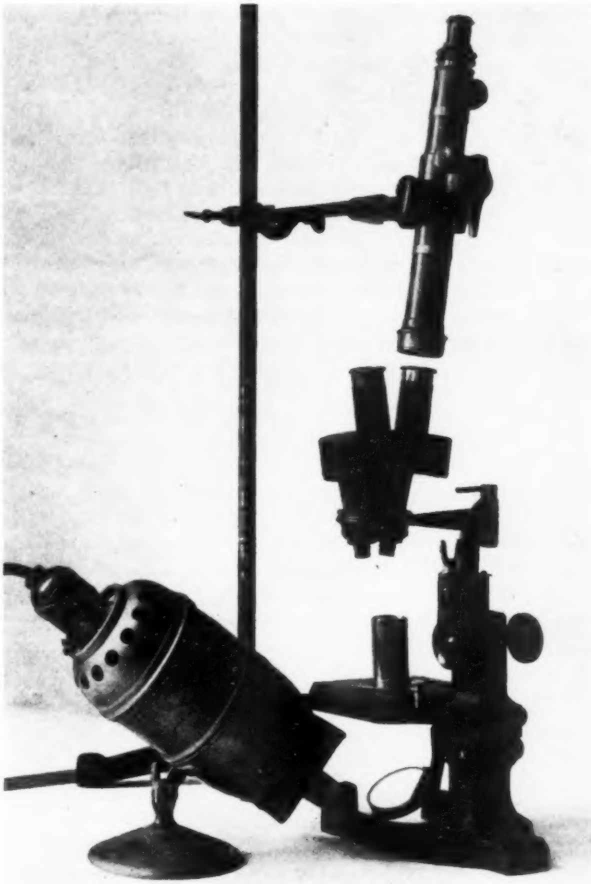

FIG. 1.—The straightedge, which can be seen on the table in contact with the base of the stand in the background at the left edge of the picture, extends to the left a considerable distance beyond what is shown.

Focus the eyepiece of the telescope carefully on its cross-hairs and focus the telescope on some distant object. Focus the microscope roughly on the cross-hairs in the field, then bring the telescope into position a little distance above one of the eyepieces of the microscope, with its long axis approximately continuous with the axis of that eyepiece. Look through the telescope and focus the microscope until the cross-hairs in the field can be seen sharply through the telescope. As the cross-hairs in the field are very delicate, this can be done most rapidly by focusing on the edge of the diaphragm on which they are mounted. When the focus has been found bring the telescope as near the eyepiece of the microscope as possible without getting it too near to be slid over to the other eyepiece. Then bring the vertical cross-hairs in the field and in the telescope as nearly into coincidence as possible, either by moving the field or by swinging the telescope to right or left around the long axis of its supporting arm. Then carry the telescope over to the other eyepiece by moving the stand along the straightedge, being careful that the stand is not rotated, and make the same adjustment. If the two vertical cross-hairs are still parallel to each other the prisms are in adjustment. If not, they must be adjusted by partly taking apart the prism case.

For this correction it is advisable to return the instrument to the maker. An error in this adjustment is probably very injurious to the eyes.

Another method suggested for making this test is to use a cross-hair eyepiece in the binocular microscope. Attach rigidly to the eyepiece a long stiff wire turned up at the ends. Make the cross-hair parallel with itself when the eyepiece is in each tube by sighting along this wire on some distant object and check with a fixed straight line in the field as in the previous method.

Conclusions.—From what has been said about the first adjustment, two conclusions seem obvious.

One is that inasmuch as the adjustment depends on the focus the binocular microscope is a very individual instrument, and anyone who has to work much with it should have one for his special use and keep it adjusted.

The other conclusion is that every binocular microscope should be equipped with a 0.040-inch or 0.055-inch jeweler's screw driver.

I should like to urge upon those working steadily with the microscope the importance of taking from the beginning, and before their eyes begin to bother them, all possible measures to protect their eyes.

As stated in the foregoing, not enough is known about the proper conditions of using microscopes in general to give a basis for many rules. In addition to the precautions enumerated, however, one that seems pretty well established is the importance of protecting the eyes from other light than that coming through the microscope. A simple means toward this end is to string a cord or wire above the desk in front of the microscope and hang from it to below the level of the eyes a curtain

of some practically opaque black material like velveteen. If the light used on the object under examination is transmitted through the object from below the stage, let the curtain hang down to the level of the stage. If the light is reflected from the object on the stage the bottom of the curtain will have to hang high enough not to cut off the light. For this reason it is in many cases an advantage to use artificial light. But do not let light from the lamp come directly to the eye. Also avoid any white sheet of paper or other bright spot on the desk near the microscope where it can be seen while you are looking through the microscope. Another simple method of protecting the eyes when using the monocular microscope is to have a flap projecting to one side from the top of the microscope so as to cover the eye not looking through the microscope. An easy way of making this is to twist a piece of wire to leave a loop at one end and sew opaque black cloth over this loop.

More complete protection is obtained by cutting one side out of a box, and cutting a hole in the bottom that will fit over the top of the microscope leaving the open side of the box toward the observer, so that he can insert his head. Blacken the inside of the box with a dead black paint which can be made by mixing lampblack with lacquer.

The illumination of the field itself should not be more than is necessary for seeing clearly. Here, too, artificial light, which can be controlled by placing different thicknesses of glass in front of it, and by varying the distance of the source from the microscope, is an advantage. A simple device for controlling the amount of illumination, devised by C. S. Ross of the U. S. Geological Survey, is a pair of superimposed and concentric metal disks placed on the front of the lamp, each with alternate radial segments cut out, one fixed, the other revolvable in front of it like the draft regulators on some stoves. The amount of overlap of the solid segments of one on the open segments of the other determines the area of opening through which light is transmitted and thus the intensity of illumination.

Marcus I. Goldman

U. S. Geological Survey

DISCUSSION

ON "KEROGEN"

To the editor

DEAR SIR: Mr. Earl A. Trager's article upon "Kerogen and Its Relation to the Origin of Oil" is very interesting, since he has studied oil shales in the only way that can yield definite results, i.e., in microscopic sections. When such research work is conducted in co-operation with a chemist who makes the necessary analyses, data of great importance are invariably forthcoming.

Furthermore, the author illustrates his paper by a series of excellent microphotographs which are very easy for anyone who has conducted similar researches to understand and appreciate.

While agreeing with many of the author's conclusions, there are several points upon which a sympathetic criticism seems to be called for. The word "kerogen," for instance, is now obsolete, since we have learned a great deal about it in the last eight or nine years, and are now able to define it more closely and to distinguish between different substances which were at one time all classed as "kerogen." Thus, the so-called "kerogen" globules of a torbanite are quite different from the "kerogen" of an oil shale, the first having been developed *in situ*, while the latter is the colloidal combination of the fine adsorbent matter of the shale with an inspissated petroleum which may have migrated for a great distance before reaching its present position. Thus it is only in torbanites that definite bodies, or globules, of the so-called "kerogen" can be identified.

In the colored figures, 4 and 5, given by Mr. Trager, jetonised vegetable matter has been mistaken for "kerogen," and the "alteration" noted in Figure 5 is really the cuticle of the vegetable fossils. In Figures 11 and 12, the "pieces of kerogen" are not globules such as one finds in a torbanite, but solid pieces of rock; they may be, and probably are, impregnated with inspissated petroleum, but they were solid bodies when the rock was formed. No "kerogen" *globule* ever disturbs the bedding, but develops across planes of lamination.

Much of the confusion that has arisen about "kerogen" has been caused by failing to distinguish the gels of a torbanite from the adsorbed petroleum of an oil shale.

Mr. Trager is right in distinguishing "kerogen" from resin, and in doubting an algal origin, but the "kerogen" of oil shales is not an intermediate stage between plants and petroleum, but a final stage of petroleum. The "kerogen" of a torbanite can, however, be regarded as an intermediate stage, because it shows how oil is formed, but the action has been arrested and cannot be continued.

As the writer expressed it in a recent paper, "oil shale represents petroleum dead and buried, torbanite represents petroleum still born."

E. H. CUNNINGHAM CRAIG

September 30, 1924

REVIEWS AND NEW PUBLICATIONS

THE OCCURRENCE OF OIL AT COMMODORO RIVADAVIA, ARGENTINE, PATAGONIA

Cambios in el Concepto de las Condiciones Geologicas del Yacimiento Petrolifero de Comodoro Rivadavia (Communicatiôn Preliminar). By ANSELMO WINDHAUSEN. Boletin de la Academia Nacional de Ciencias de Córdoba, Buenos Aires, 1923.

In this important paper Dr. Windhausen combats, apparently with good reason, the current notion that the Comodoro Rivadavia oil has accumulated in horizontal lenticular beds.

The stratigraphy of the field is now fairly well known from a comparison of the well records with sections exposed along the Atlantic Coast and some of the river valleys of the interior. In summary it is as follows:

Tertiary:

Patagonian formation—marine.

Erosional unconformity.

Eocene—mammal-bearing shales and light-colored tufts of continental origin, with *Notostylops*, *Pyrotherium*, and *Colpodon*.

Thickness up to 140 meters; in places entirely eroded away before the deposition of the Patagonian formation.

Angular unconformity.

Upper Cretaceous (dinosaur-bearing beds):

Clay shales, cut by gypsum veins, alternating with cross-bedded white sandstones. Thickness about 200 meters.

Salamquean (Danian in age)—approximately equivalent to the Rochanean of the valley of the Rio Negro. Marine glauconitic gray-green sandstones with intercalations of shaly beds and calcareous geodes. Near the base is an oyster bed of hard fissile shale which is used as the key horizon in the well records. Thickness, 120–30 meters.

First oil-bearing horizon, glauconitic sandstones.—Windhausen considers that the oil has immigrated into this horizon from lower beds. Oil irregularly distributed. The horizon contains lignite and is considered transitional from the continental beds below to the marine beds above.

Clay shales of continental origin—unfossiliferous.

Senonian:

Blue-gray shales and intercalated sandstones with shows of oil.

Second oil-bearing horizon.—A sandstone 80–90 meters below the base of the Salamquean.

Sandy strata with oil shows. Thickness, 50–60 meters.

> *Third oil-bearing horizon.*—A thin sand apparently not encountered in all wells. Blue compact shales with lignite and intercalated sandstones. Thickness over 100 meters. The lowest strata reached in the wells, some of which are over 2,900 feet in depth. This member has not yielded any fossils.

Two epochs of folding are shown: the one, more intense and accompanied by faulting, occurred near the end of the Cretaceous; the other, more gentle and with broader structures and only exceptional faulting, occurred in Tertiary or post-Tertiary. Windhausen's contour map shows a main northeastward-trending anticline 7 miles in length with its axis parallel to and close to the coast line. Superimposed on this are three domes. A barren syncline separates the main fold from the anticline of the Astra pool to the north. The highest part of the main structure is about 3 miles north of the town of Commodoro Rivadavia. The amount of closure indicated is from 50 to 150 meters. The dip in the Cretaceous is three times as great as in the Tertiary. Water has been found in the lower part of the southwest side of the main structure.

The writer advances some reasons for holding that the physiography may give some clue to the structure.

It seems to the reviewer that if Windhausen's views are correct there is reason to hope that Patagonia may produce more oil than her two present fields (Comodoro Rivadavia and Playa Huincul) have so far promised. If the surficial Tertiary is really folded, those folds can be found. Buried folds and unconformities add complexities to the problem, but we encounter the same in some parts of the United States and are gradually successfully overcoming them.

CHARLES LAWRENCE BAKER

THE ASSOCIATION ROUND TABLE

CLAIMS AGAINST MEXICO

American Association of Petroleum Geologists

GENTLEMEN: Under Conventions concluded between the United States and Mexico on September 8 and 10, 1923, respectively, provision is made for the organization of two Mixed Claims Commissions to hear and determine all claims of citizens of the United States against Mexico. I hand you herewith pamphlet containing copies of these Conventions, together with the Rules adopted by the respective Commissions.

It will be observed that the time for filing claims under the General Claims Commission expires August 30, 1925. The time for filing claims under the Special Claims Commission, which deals with revolutionary claims, expires in August, 1926. This Agency has been organized by the Department of State of the United States to represent the Government and claimants in the presentation of claims against Mexico under these Conventions. A large number of claimants seem not to have been advised of the organization of the Commissions and of the Agency. It should be observed that unless claims are filed before this Commission within the time specified they are by the terms of these Treaties forever barred. The Agency is very desirous, therefore, of bringing these facts to the attention of any individual or corporation which has a claim against Mexico arising since 1869. It is suggested that it might be of great benefit to the members of your association if these facts could be brought to their attention, in order that they might take such steps as they might be advised for the protection of any claim which they might have against Mexico.

Very truly yours,

HENRY W. ANDERSON
Agent for the United States

MIXED CLAIMS COMMISSIONS
FIFTEENTH AND K STREETS
WASHINGTON, D.C.
January 17, 1925

[The pamphlet referred to is Treaty Series No. 678, which should be asked for in correspondence with Mr. Anderson.—J.H.G.]

ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA

The Annual Meeting of the Geological Society of America was held at Cornell University, Ithaca, New York, on December 29, 30, and 31, 1924. Members of the American Association of Petroleum Geologists who read papers in-

cluded Eliot Blackwelder, E. De Golyer, J. F. Kemp, K. F. Mather, H. D. Miser, Wilbur A. Nelson, Sidney Powers, A. C. Trowbridge, W. H. Twenhofel, E. M. Spieker, and David White. In addition, progress reports on different activities of the National Research Council were given by David White, W. H. Twenhofel, and K. C. Heald.

Of particular interest to oil geologists was a paper by E. De Golyer, in which he sketchily discussed "The Application of the Eotvos Balance and of Seismos to the Discovery of Conditions Favorable for Oil Accumulation and Particularly to Finding Salt Domes"; and one by Sidney Powers, on "Structural Conditions in the Mid-Continent Field," wherein he pointed out the urgent need for better information than is now available regarding the origin of these structural features, and outlined his own theory that they are due primarily to the recurrent uplift of granite hills, which are features of the pre-Cambrian floor of the Mid-Continent. Papers whose publication should give data regarding the geologic structure or stratigraphic conditions in regions known to be potentially oil-yielding, or of areas whose geology is so little known that any additional evidence may help in forming judgment concerning oil possibilities, include: "Central Asia in Cretaceous Time," by Charles P. Berkey and Frederick K. Morris; "Discovery by Geophysical Methods of a New Salt Dome in the Gulf Coast," by E. De Golyer; "Erosion in San Juan Canyon, Utah," by Hugh D. Miser; "Two New Volcanic Ash Horizons in the Stones' River Group of the Ordovician of Tennessee," by Wilbur A. Nelson; "Structural Geology in the Mid-Continent Region: A Field for Research," by Sidney Powers; "A Possible Factor in the Formation of Dolomite," by Percy E. Raymond; "Origin of the Dolomite Limestone at Argentine, Kansas," by Austin F. Rogers; "The Reynosa Formation in Southwest Texas," by A. C. Trowbridge; "The Granite Intrusive of the Rose Dome, Woodson County, Kansas," by W. H. Twenhofel; "Projected Oceanographic Investigations," by David White; "The Tectonic History of Central Asia," by Charles P. Berkey and Frederick K. Morris; "Active Thrust Faults in San Benito County, California," by Paul F. Kerr and Hubert G. Schenck; "Geologic Mapping with Airplane Photographs in Arizona," by Edward Sampson; "Cretaceous and Tertiary Formations of the Wasatch Plateau, Utah," by E. M. Spieker and John B. Reeside, Jr.; "The Topography of Active Faulting in California," by Robin Willis; "The Physiography of the California Coast Ranges," by Robin Willis; and "Pleistocene Foraminifera from the Palos Verdes Hills of California," by J. J. Galloway and S. G. Wissler.

The meeting was the occasion for the presentation of the Penrose Medal for outstanding contributions in geology by the Society of Economic Geologists. The award was made to Professor T. C. Chamberlin. Unfortunately, Professor Chamberlin, who had come to Ithaca expressly to receive the medal, suffered injuries due to a fall the day before the presentation which confined him to the hospital, and the medal was presented through Professor Stuart Weller, who acted as Professor Chamberlin's proxy.

PAYMENT OF DUES

A number of members have paid dues in advance, and one of them writes as follows: "I was late in paying dues last year, so I am making up for it this time."

Will other tardy members please take note?

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This publication does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to Charles E. Decker, Norman, Oklahoma.

(Names of sponsors are placed beneath the name of each applicant.)

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PHOTOGRAPHS OF MEMBERS

A suggestion was made a short time ago by Mr. David White that for many reasons it would be very desirable to have a file of photographs of our members, as complete as possible. This suggestion has been favorably received by members of the executive committee, and we are beginning now to collect them. To file 1,200 photographs with facility requires that they shall be of uniform size, not over 3×5 inches; $3 \times 4\frac{1}{2}$ inches is a good size. Fairly rigid paper should be used and gloss finish is preferable. Place your name and the date of the picture on the back, and send it to Charles E. Decker, 508 Chautauqua Avenue, Norman, Oklahoma.

AT HOME AND ABROAD

DOUGLAS R. SEMMES sailed for France December 27 and will continue to Bombay, India, where he will make a petroleum reconnaissance of one of the native states. Mr. Semmes expects to return to New York April 1.

K. B. NOWELS has been transferred to the new Bureau of Mines Experiment Station at Laramie, Wyoming.

JAMES GILLULY, of the United States Geological Survey, has been mapping the San Rafael Swell and the Crescent structure near Cisco and Pleasant, Utah.

GAIL F. MOULTON, geologist on the staff of the Illinois Geological Survey, has resigned from the United States Geological Survey.

W. W. RUBEY, who has recently completed field mapping in the Black Hills region, has returned to the United States Geological Survey offices in Washington.

M. N. BRAMLETTE is a graduate student in the Department of Geology, Yale University.

A. W. DUSTON, president of the Okmulgee Geological Society, has been elected president of the Okmulgee Kiwanis Club for the coming year.

H. N. (TURK) URI, consulting geologist of Okmulgee, Oklahoma, is the proud father of a fine baby boy.

DAVE M. LOGAN has been elected a member of the Oklahoma State Legislature. If any geologist has any particular measure he wants put over, call on Dave.

C. N. GOULD, state geologist of Oklahoma, gave a very interesting talk on Oklahoma geology and its problems to the Okmulgee Geological Society on November 21.

A committee of Okmulgee geologists consisting of A. W. DUSTON, chairman; LOUIS ROARK; R. W. CLARK; and D. H. RADCLIFF, recently made a report to the city commissioners and Chamber of Commerce of Okmulgee on the possibilities of obtaining a water supply for Okmulgee from wells. The value of geology for purposes other than finding oil is rapidly being recognized by the various communities where geologists are located, and geologists are becoming active civic workers.

W. L. Ainsworth, Jr., consulting geologist, of Wichita, Kansas, has been active for some time in the movement for a better water supply for Wichita. Following his work the City Commission recently arranged for a detailed investigation of water resources by the State Geological Survey and a report prepared by Raymond C. Moore has been submitted to the city.

The following note in the last issue of the *Union Oil Bulletin* of the Union Oil Company of California is of interest to petroleum engineers and geologists: "Effective November 1, those men formerly known as resident geologists and employed in subsurface work and engineering in connection with drilling and production will be reclassified and will be known as petroleum engineers, and will be responsible to the manager of field operations through the office of the division superintendents. Each division will have a division petroleum engineer, and in addition to the recognized duties of a petroleum engineer he will act as assistant to the division superintendent. R. R. Templeton is appointed chief petroleum engineer, with headquarters in Los Angeles head office, subject to the manager of field operations."

A meeting of the Branner Club was held in Los Angeles on the evening of December 19, at which time the members were addressed by Professor William Morris Davis, of Harvard University, on "The Physiography of the Great Basin."

R. C. Stoner has returned from Mexico City, where he spent several years for the Standard Oil Company of California, and now has his headquarters in San Francisco.

D. M. Collingwood, until recently head of the Oil and Gas Division of the State Survey of Illinois, joined the Geological Staff of the Sun Oil Company at Dallas on December 1, 1924.

Theron Wasson, chief geologist of the Pure Oil Company, is spending several months in Venezuela, going over property of the Orinoco Oil Company, a subsidiary of the Pure Oil Company.

H. D. Easton, consulting geologist, Ardis Building, Shreveport, Louisiana, is continuing his investigations in wildcat territory in Mississippi. He is directing a second test of the area near Charleston, Tallahatchie County, on the strength of a showing in that locality a year ago, in a sand below the Selma chalk at a depth of about 2,600 feet.

S. C. Stathers, chief geologist of the Standard Oil Company of Louisiana at Shreveport, has returned from a vacation spent among homefolks in West Virginia.

J. Wallace Bostick, of Tulsa, Oklahoma, and F. X. Bostick, paleontologist with the Standard Oil Company of Louisiana at Shreveport, returned to Amite, Louisiana, to celebrate Christmas.

L. A. Barton, of Shreveport, and M. W. Grimm, of the Minerals Division of the Louisiana State Conservation Commission at Shreveport, have been duck-hunting along Louisiana bayous. They enthusiastically report as much success in this recreation as in the pursuit of geological structures in the same territory.

A. L. Solliday, geologist for the Dixie Oil Company, stationed at Magnolia, Arkansas, spent the holidays at his former home in Watertown, Wisconsin.

J. P. D. Hull, geologist for the Louisiana Oil Refining Corporation at Shreveport, recently made a trip of a few weeks in the territory from Texarkana to San Antonio, Texas.

A party of geologists composed of L. W. Stephenson, of the United States Geological Survey; Sidney Powers, of the Amerada Petroleum Corporation at Tulsa, Oklahoma; H. G. Schneider, of the same organization at Shreveport, Louisiana; A. L. Selig, of the Atlantic Oil Producing Company at Shreveport; and W. C. Spooner, of Shreveport, visited a number of the interior salt domes of Louisiana last December, and exchanged professional opinion particularly with regard to the Cretaceous exposures on these structures.

L. S. Harlowe, geologist for the Louisiana Oil Refining Corporation at Shreveport, made a short field trip into the Coastal Plain of Alabama last December.

Theo. A. Link returned to Colombia, S.A., in January. During the last four months of 1923 he was on a vacation and spent his time working at the University of Chicago on Miocene fossils collected by him in Colombia. A seven-and-a-half-pound boy also arrived during the vacation. His name is Thomas Rollin Link.

J. D. Sears made a talk in New York, December 2, before the American Society of Mechanical Engineers on "Engineers and the American Petroleum Situation."

P. V. Roundy was in Pawhuska, Oklahoma, December 14, to attend a sale of Osage oil leases at the request of the Office of Indian Affairs.

G. H. Girty is spending a two months' vacation in the Barbadoes.

Arthur Knapp recently gave a talk to petroleum geologists of the United States Geological Survey on "Petroleum Economics."

J. B. UMPLEBY recently visited the United States Geological Survey for conferences regarding the Bradford oil sands.

W. T. THOM, JR., left Washington on January 14 for Oklahoma, where he will be engaged in compiling a structure map of the northeast quarter of the state in co-operation with the State Survey. He will address meetings of the Okmulgee and Tulsa geological societies in connection with the project. He will be gone until some time during the first half of February.

PROFESSIONAL DIRECTORY

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